IMPACT OF STONE QUARRY OPERATIONS ON PARTICULATE LEVELS AND COMMENTS

Document No. 83/14

ENR

Illinois Department of
Energy and Natural Resources

James R. Thompson, Governor
Michael B. Witte, Director

Printed by the Authority of the State of Illinois

Doc. No. 83/14

June 1983

Impact of Stone Quarry Operations on Particulate Levels and Comments

James R. Thompson, Governor
State of Illinois

Michael B. Witte, Director
Illinois Department of Energy
and Natural Resources

FOREWORD

On March 4, 1980 the Illinois Institute of Natural Resources (now the Department of Energy and Natural Resources) contracted with PEDCo Environmental, Inc., to do a study that measured the particulate levels from stone quarry operations. This study was one of the first comprehensive analyses of a quarry operation on air quality. The field study was conducted in a quarry in the Chicago area and was completed by August 30, 1980.

The following groups or organizations participated in this study: Illinois Department of Energy and Natural Resources (ENR), Illinois Environmental Protection Agency (IEPA), Illinois Association of Aggregate Producers (IAAP), Materials Service Corporation, and PEDCo Environmental, Inc.

Because this study was one of the first to look at quarry emissions in detail, many questions were raised regarding correct monitoring techniques, field monitoring locations, data gathering and final analysis. As with every field study, there are differing views (pros and cons) of the correct way to collect and analyze the data.

This report presents the PEDCo study as well as two opposing viewpoints of the study and its final results. The report is broken down into four sections: the first section is the PEDCo study itself; the second section is a critique of the PEDCo study done by Dames and Moore, Inc., for the IAAP; the

third section contains IEPA comments of the PEDCo study; and Section 4 is the amendment to Rule 203(f) of IPCB Chapter 2, Fugitive Particulate Emissions from Industrial Sources, dated October 4, 1979.

Section 172 of the Clean Air Act requires that the State of Illinois provide for the attainment of the National Ambient Air Quality Standard (NAAQS) for total suspended particulate (TSP) by December 31, 1982. The provisions for attainment are to be included in the State Implementation Plan (SIP), which must contain emission limitations, schedules of compliance, and other measures as may be necessary. IEPA identified geographical areas which had not attained NAAQS TSP levels and sources which contributed to high TSP levels. The IEPA found that the highest monitored TSP levels were generally located in the vicinity of large industrial sources of fugitive emissions. These sources included the following: stockpiles, plant roads, conveyor transfer points and material handling. As a result of this data, IEPA proposed to amend the Illinois Pollution Control Board's (IPCB) fugitive particulate emissions standard.

On September 13, 1978, IEPA filed a proposal to amend Rule 203(f) of the Air Pollution Control Regulations (Chapter 2 of the Board's Rules and Regulations). The Board then docketed the proposal as R78-11 and ordered hearings set. On March 15 and 22, 1979, IEPA submitted revisions to its proposal, which were published in the Board's Environmental Register. Public hearings were held at the following locations:

October 30, 1978	Springfield
November 14, 1978	Chicago
December 6, 1978	Peoria
December 8, 1878	Chicago

Pursuant to Public Act No. 80-1218, Ill. Rev. Stat. ch. 96 1/2, §7401 _et seq._, the Illinois Institute of Natural Resources on March 28, 1979, filed IINR Doc. No. 79/06, _The Economic Impact of Proposed Regulations to Reduce Particulate Emissions from Steel Mills and Industrial Fugitive Sources_. Hearings on the economic impact were held in the following locations:

May 3, 1979	Oglesby
May 4, 1979	Chicago
May 16, 1979	Belleville
May 17, 1979	Springfield

On March 29, 1979 the Board proposed an Interim Order to meet the federal deadline for submittal of SIP revisions pursuant to the Federal Clean Air Act. On July 12, 1979 the Board proposed a Final Draft Order and published it in the _Illinois Register_ on August 10, 1979, pursuant to the Illinois Administrative Procedures Act, Ill. Rev. Stat. Ch. 127, §1001 _et seq_. The public comment period ended September 24, 1979. On October 4, 1979 the Board adopted a Final Order in this proceeding. Section 4 is the IPCB final order on Fugitive Particulate Emissions from Industrial Sources. Paragraph 3(f) of the order is probably the most important in terms of how mining operations shall reduce F.P.M. Paragraph 3(f) states:

> _The sources described in paragraphs (f)(3)(A) through (f)(3)(E) shall be operated under the provisions of an operating program prepared by the owner or operator and submitted to the Agency for its review by December 31, 1982. Such operating program shall be designed to significantly reduce fugitive particulate emissions._

With this rule in hand, all industrial sources such as quarries that were in the areas listed in Section 4 must submit plans to IEPA on how to maintain and reduce their FPM problems.

Prior to this new IPCB rule, IEPA had performed air quality dispersion modeling analyses which indicated that fugitive dust emissions from quarries contribute to violations of particulate standards. However, IEPA had not actually measured the generation of emissions from quarries and the dispersion of these emissions away from the site. IEPA, with the funding assistance of ENR and the cooperation of the IAAP and one of its member quarries, decided to perform a field study to measure ambient particulate levels from a stone quarry. PEDCo Environmental, Inc., of Kansas City, Missouri was hired to perform this analysis. The first section of this document represents the results of PEDCo's air quality analysis of the quarry.

CONTENTS

IMPACT OF STONE QUARRY OPERATIONS
ON PARTICULATE LEVELS

by

PEDCo Environmental, Inc. [1)]

Project No. 10.085

1) Prepared under contract with the Illinois Department of Energy and Natural Resources as project number 10.085; to PEDCo. Environmental, Inc., Kansas City, Missouri.

CONTENTS

CONTENTS (continued)

FIGURES

TABLES

TABLES (continued)

SECTION 1

INTRODUCTION

1.1 EXECUTIVE SUMMARY

Regional air quality dispersion modeling analyses performed by Illinois EPA have indicated that fugitive dust emissions from quarries contribute to violations of particulate standards in several nonattainment areas throughout the state. However, the generation of emissions from quarries and the dispersion of these emissions away from the site are not well understood. The primary purpose of the present field study was to confirm or refute these modeling results by measuring the actual impact of a typical stone quarry on ambient particulate levels. It was the first comprehensive air quality analysis of a quarry in the country.

The most direct method of measuring the net contribution is by sampling concurrently upwind and downwind of a quarry at distances that would be considered ambient rather than source sampling. These distances have been estimated at 0.5 to 1.0 km from the major emission points at the quarry.

A secondary purpose of the study was to determine the relative impacts of suspected major emission sources at the quarry. This could not be done with the same sampling program as described above, so a separate sampling effort was designed to assess relative impacts.

Another secondary purpose of the study was to estimate the effectiveness of commonly-used control measures in reducing the impact of quarry operations on particulate concentrations. By applying control measures during part of the sampling and no controls during the other part, the effectiveness was determined on both the individual emission sources and on quarry emissions as a whole.

All three objectives required the collection and analysis of extensive particulate air quality data and close monitoring of quarry operations and meteorological conditions at the times of the sampling.

The quarry sampled was found to produce an average impact of 30 $\mu g/m^3$ at 0.5 km and 15 $\mu g/m^3$ at 0.7 km on days with quarry

operations. The crusher/storage area was identified as the largest contributing source. Watering, as applied at the test quarry, did not reduce the overall impact around the quarry but did reduce concentrations immediately downwind of haul roads and the crusher/storage area by 31 and 26 percent, respectively. These conclusions are all site-specific and cannot be extrapolated quantitatively to other quarries.

1.2 SELECTION OF QUARRY FOR SAMPLING

In the original specifications for this study (Draft Scope of Work with cover letter dated December 24, 1979), the scope was limited to sampling at a single quarry. It was anticipated that several quarries in or near urban areas would be visited to select the one most appropriate for sampling. Proximity to an urban area was desirable because most particulate nonattainment areas in Illinois are urban, and pollutant dispersion characteristics may vary between rural and urban areas.

Participants in the selection process were the Illinois Institute of Natural Resources (now the Department of Energy and Natural Resources), Illinois EPA, and PEDCo. Representatives of the Illinois Association of Aggregate Producers and one of its member companies assisted by contacting industry representatives to find potentially suitable quarries for sampling. Primarily because of time constraints (so the study could be completed within the 1980 fiscal year), only one quarry was visited. It met the criteria for size, representative operations, good sampler locations, and ability to control or not control dust emissions. Its only drawbacks were location in a rural area and the presence of some nonquarry-related sources--specifically, an asphalt batch plant and an unpaved road. Rather than wait for other volunteered sites for comparison, this quarry was selected.

The name and location of the quarry have been withheld in this report as part of the agreement by the quarry operator to participate. A map of the quarry, prepared from an aerial photo, is shown in Figure 1.

The quarry has an annual production of 400,000 tons of crushed limestone. The stone is broken by blasting, usually once per week. The broken stone is loaded from either of two benches onto 25-ton capacity haul trucks with a front-end loader. The haul distance averages 0.4-0.5 mi. The stone is dumped into a hopper above the primary crusher and is then conveyed successively to the secondary crusher, tertiary crusher, and/or temporary ground-level storage bins located around the perimeter of the crushers. From the bins (containing various sizes of rock), the rock is either loaded directly onto a customer's truck or carried by front-end loader to the larger open storage piles to the north

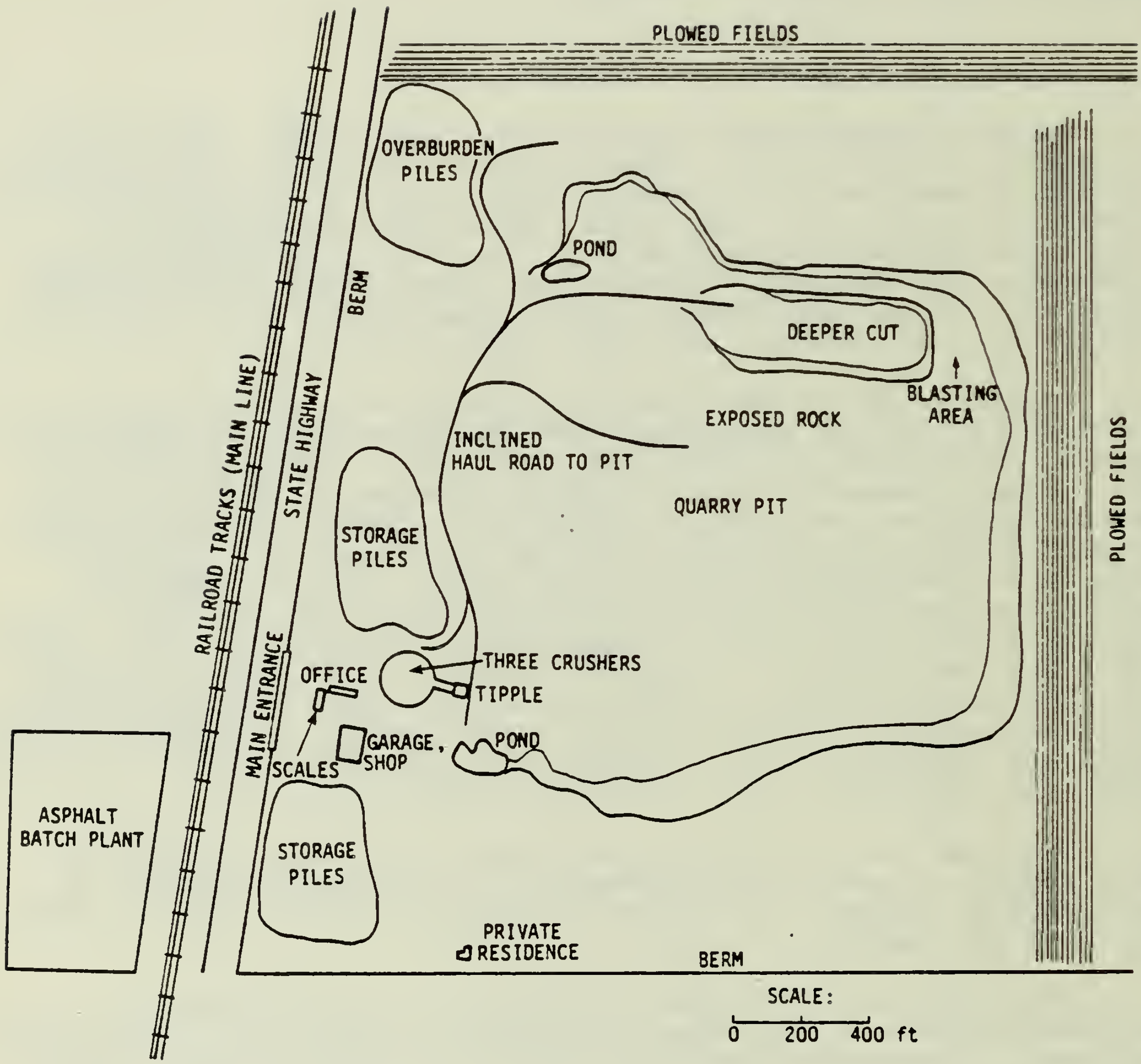


Figure 1. Map of Rock Quarry.

and south of the crusher area. Customer trucks are weighed as they leave the quarry.

The quarry is relatively shallow (about 60 ft. deep) and is located in an agricultural area with flat terrain.

1.3 SCHEDULE

The contract for fieldwork at the quarry, laboratory analysis of filters, and data analysis was signed in mid-March. The first task was preparation of a detailed study design specifying the following:

- Conceptual design for study
- Locations of air quality and meteorological sampling sites
- Sampling equipment
- Number of samples and schedule
- Independent variables to be monitored (source-related and meteorological)
- Control measure activities
- Quality assurance procedures
- Data analysis procedures

The draft study design report was distributed on April 9 for comments; meetings were held in Chicago on April 14 and 18 to discuss the proposed design; and final revisions were completed and approved by April 23. Most of the information in the study design report, which had limited distribution, is presented in the present report with necessary modifications to reflect changes in the study as implemented.

Sampling equipment was installed and calibrated on May 1 through 5, and sampling began on May 6, 1980. Unwind-downwind sampling continued daily, including weekends, through July 31. A total of 74 sampling sets were generated (out of a total of 87 days possible).

Samples were sent to PEDCo's laboratory periodically throughout the three months of sampling, so all data were available from the lab by August 20. Data analysis began in early August and continued through September 23, when the draft report was completed. This schedule is shown in Figure 2.

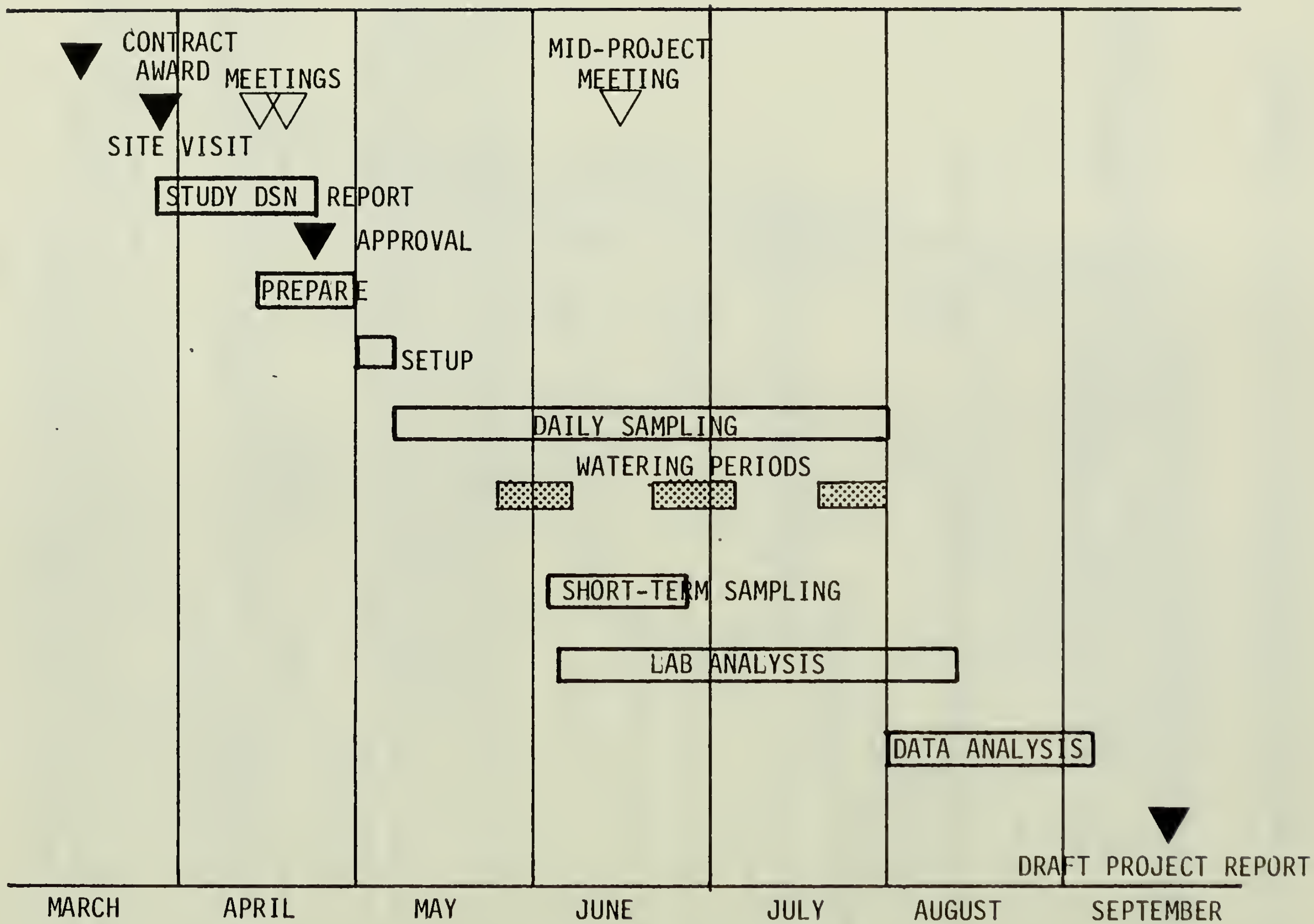


Figure 2. Schedule for quarry study.

The schedule is described here mainly to emphasize the short time frame in which the study design and data analysis took place. If more time were available, additional more detailed analyses could have been performed with the data. Most of the data from the study is presented in this report or its appendices so that readers can perform such analyses that are of interest to them.

1.4 PRODUCTS

The data analyses included in this report that form the basis for most of the conclusions in Section 7 are:

- Comparison of average downwind particulate impacts for each of three conditions: good dust control by frequent watering (26 days), poor dust control with no watering (27 days), and no quarry operations (21 days).
- Effect of meteorological variables on net concentrations.
- Effect of quarry activity levels on net concentrations.
- Relative impacts of haul roads, paved roads, and crusher/storage area on particulate concentrations during periods of simultaneous sampling.
- Effectiveness of control measures (watering) in reducing concentrations downwind of individual sources and downwind of the entire quarry.
- The percent of particulate in the less than 15 μm size range, and how that percent is affected by meteorological variables, distance from source, and control measure application.

SECTION 2

SAMPLING METHODOLOGY

2.1 UPWIND-DOWNWIND APPROACH

Upwind-downwind sampling is a standardized technique that is widely used to measure fugitive emissions from sources that cover too large an area to be temporarily enclosed or sampled isokinetically along a cross-sectional profile.[1,2] It is conceptually simple--samplers are placed on opposite sides (in the prevailing wind direction) of a well-defined emission source and operated simultaneously during a period of consistent winds. The impact of the source is the difference between the upwind and downwind concentrations. This ambient impact can be used in an atmospheric dispersion equation to back-calculate the source strength.

Other requirements of the upwind-downwind technique are that accepted ambient monitoring methods and equipment be used; sampling be for a time sufficient to collect a measurable weight; particulate samplers be at least 3.0 m off the ground to prevent local entrainment from affecting the samples; there be no interfering sources near the upwind sampler; and that source-receptor distances and initial plume (or source) dimensions be known. It is desirable for downwind sampling to be done at different distances from the source to permit an evaluation of particle deposition.

The two applications of upwind-downwind sampling used to measure overall quarry impact and the relative contributions of suspected major sources at the quarry are described in the following two subsections.

2.2 FIXED NETWORK SAMPLING OF OVERALL QUARRY IMPACT

Sampling sites designated exclusively as upwind or downwind would only be able to produce valid samples on days when winds were fairly consistently in the correct orientation for these samplers. However, if a symmetrical array of samplers is placed straddling the quarry, either group could be the downwind samplers depending on the actual wind direction for that day. Therefore, four fixed sampling sites were located at the quarry at nominal distances of 0.5 and 1.0 km to the SSW and NNE of the center of activity at the quarry. Prevailing wind direction in the area

during the months of May through July is from the SSW. Actual distances were 0.5 and 0.7 km due to physical constraints. Locations of the sampling sites are shown in Figure 3.

Winds frequently reverse over 24-hour periods so that on many days neither pair of samplers would be completely free of impact from the quarry (and therefore be valid upwind samples). To eliminate this problem and ensure virtually 100 percent usable data for the analysis of source contribution, directionally-actuated samplers were placed at each site. Directional controls (e.g., over a 90° range of wind directions) started the samplers when the wind direction was appropriate and prevented the samples from being exposed during crosswinds or periods of wind reversal.

The only significant shortcoming of this approach was that samples did not represent 24-hour time periods and therefore would not be directly comparable with ambient air quality standards or dispersion modeling results. Therefore, samplers at the same four locations were also run for the entire 24 hours, the standard time period for running hi-vols.

The locations and directionally-actuated characteristics of the sampling sites attempted to account for possible nonquarry related particulate sources in the vicinity. For example, all four sites were equidistant from the state highway and rail line (line sources), so their impacts were cancelled out when calculating net concentrations. Activity noted in nearby agricultural fields could be isolated from the measured concentrations by using a 0.5 km upwind reading for background rather than a 0.7 km reading (closer to an upwind field), or by using the readings from downwind directional samplers rather than the 24-hour samplers on days when fields near the downwind samplers impacted them during periods of wind reversal.

No method for isolating the impact of the batch plant from that of the quarry by sampler placement or operation could be determined. Therefore, activity rates at the quarry were monitored throughout the study so that they could be correlated with concentrations measured at the quarry to statistically determine whether the batch plant had an impact on these concentrations.

The unpaved road along the southern property line of the quarry was also identified as a potential major interfering source. It was requested that an additional site be located inside (to the north of) that road so that a sample free from its impact could be obtained south of the quarry on days with winds from the north. However, due to a breakdown in communications by the PEDCo staff, this site was never located. Instead, interference from this source was estimated by:

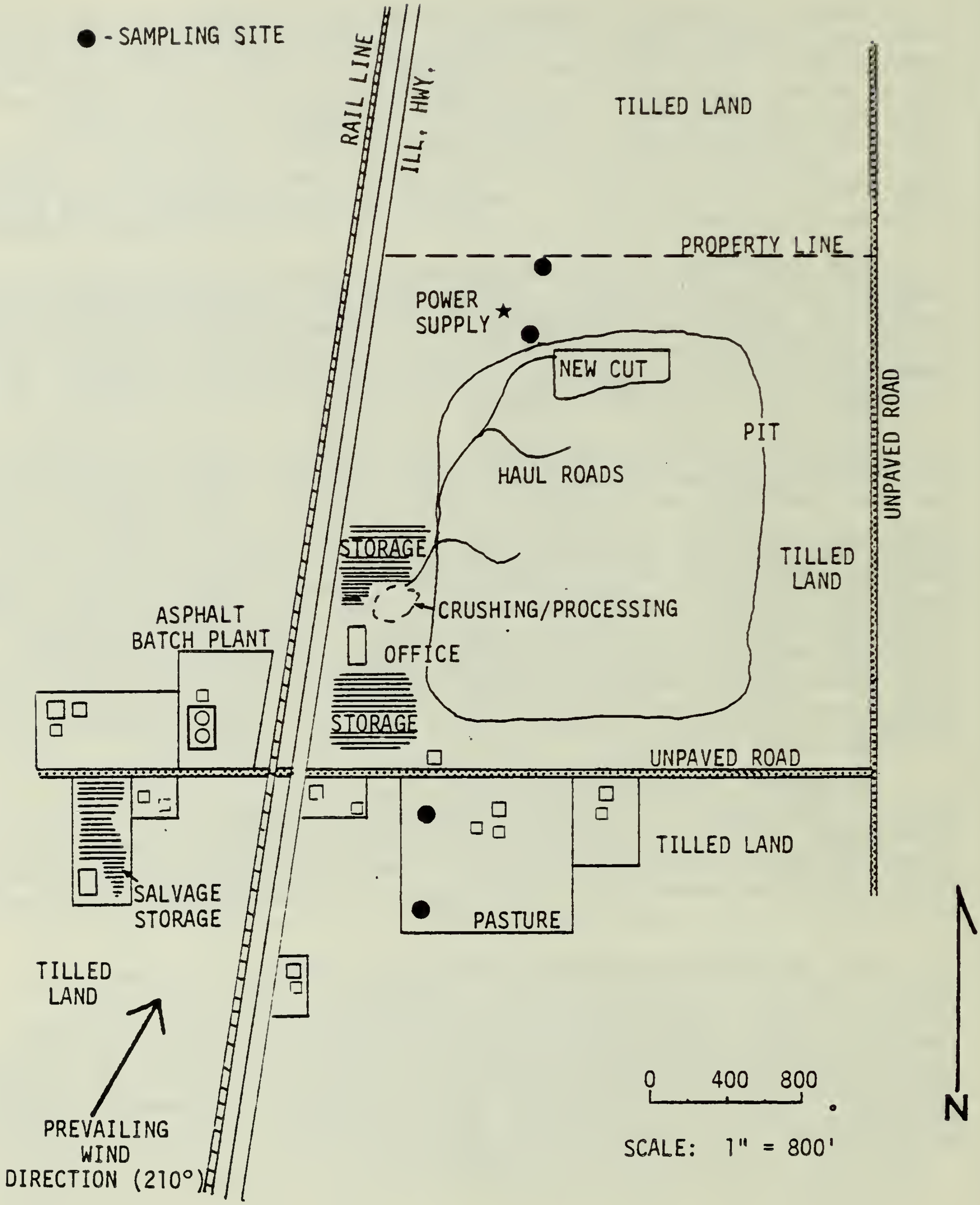


Figure 3. Locations of sampling sites at quarry.

- Comparing average quarry impact on days with winds from the south versus days with winds from the north.

- Comparing impact at the 0.5 km site (about 50 m from the road) with impact at the 0.7 km site (about 250 km from the road).

- Using daily traffic volume on the unpaved road as an independent variable in the multiple linear regression analysis of the fixed site data.

One additional type of particulate sampling was conducted at some of the fixed sites--inhalable particulate (less than 15 μm size range) was measured at the two sites nearest the quarry.

Particulate sampling was done daily from May 6 through July 31, except that leakage problems with the size selective high volume (hi-vol) inlet sections (crack in the housing) caused loss of about the first month of that data. The samplers ran from approximately 5 p.m. until the following 5 p.m., with the designated sampling date being the second of the two days.

The standard hi-vol sampler was the primary particulate sampler; it is the reference method for measuring TSP. Rooflines of the hi-vols were all aligned parallel to the prevailing wind direction so that different inlet collection efficiencies between upwind and downwind samplers were not a factor in the analysis. The General Metals Works GMWL-2000 hi-vols were equipped with Dickson pressure transducer recorders to continuously record flow rates, and running time meters to record total running time to the nearest 0.1 min. Flow rates on the hi-vols were always in the range of 40 to 55 cfm.

Wong EcoVane wind direction controls were used to actuate the directional hi-vols. Separate directional control units were required for the upwind pair of sites and the downwind pair because of the distances involved. The units were both normally set to run with a range of wind directions from 165° (SSE) to 255° (WSW), or a 90° sector centered around 210°. When the winds were from outside this sector the samplers automatically shut off. The PEDCo operator could (at the beginning of a 24-hour period) reverse the sampling direction to a 90° sector centered around 30° if the National Weather Service (NWS) forecast called for winds from that quadrant for the following day.

Andersen Model 7000 hi-vols with size-selective inlets were used to sample inhalable particulate. These units have cylindrical inlets which are not directionally sensitive and operate at a constant flow of 40 scfm.

The sampling equipment was placed on wooden platforms to elevate the sampler inlets to 3.0 m above ground level. This height is consistent with current EPA air quality monitoring guidelines. Three samplers (hi-vol, directional hi-vol, and size-selective hi-vol) were mounted on two of the platforms and two samplers were on each of the other two platforms. Photos of two of the sites are shown in Figure 4.

All samplers used 8 x 10-1/2 in. glass fiber filters. Filters with low amounts of residual chemical material in them were specified so that chemical/elemental analyses could be performed on the filters at a later date, if so desired. In particular, the blank filters had only trace amounts of Ca and Mg, the two elements most easily distinguishable in quarry emissions. Both these elements are stable on the filters in storage, so no special sample preservation procedures were observed. All filters have been shipped to Illinois EPA for safekeeping and possible further analysis.

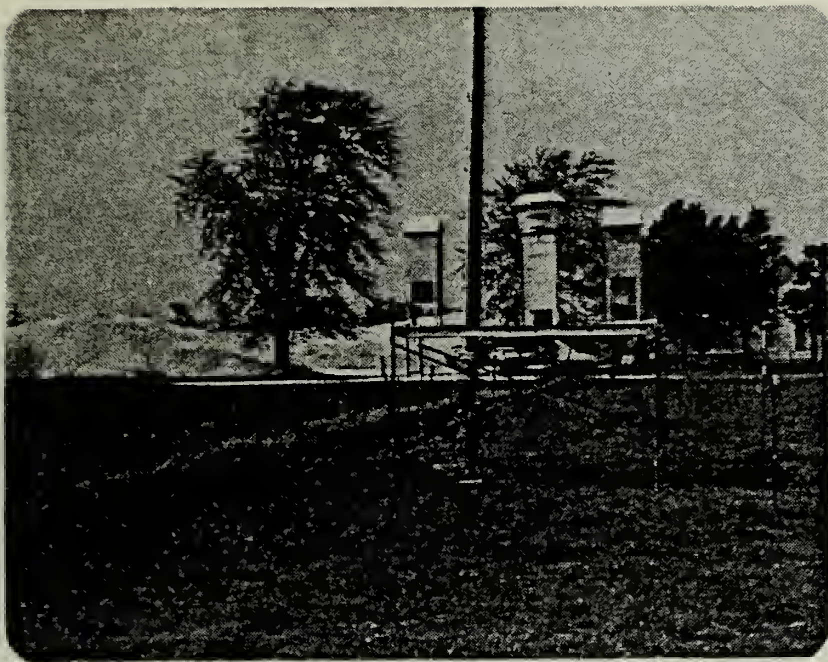
2.3 SHORT-TERM SAMPLING OF INDIVIDUAL QUARRY OPERATIONS

Upwind-downwind sampling was performed around major sources at distances much closer than 0.5 to 0.7 km to isolate the emissions from individual sources. Downwind sampling distances from different sources were kept the same and sampling periods were run simultaneously so that impacts could be compared directly.

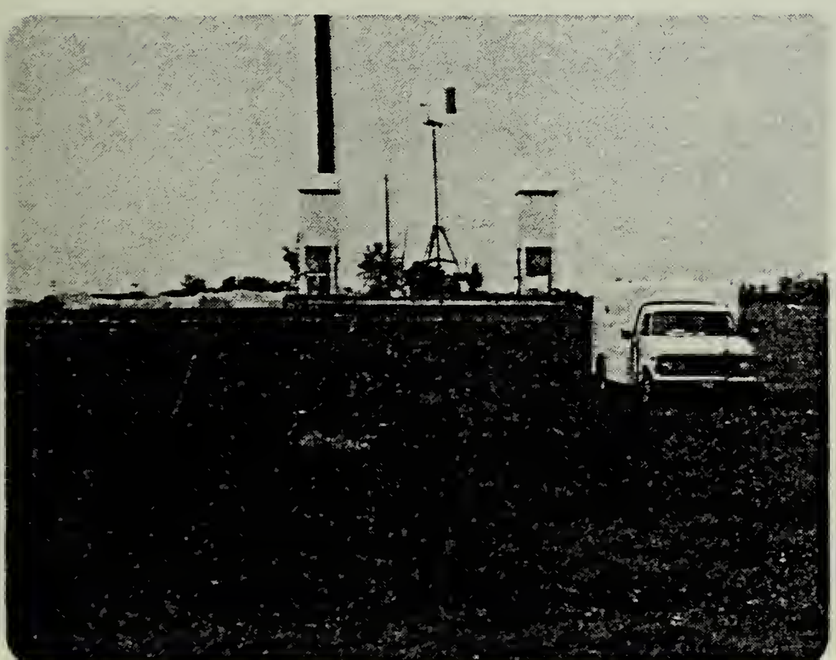
Three samplers were placed downwind of each source and three sources were sampled simultaneously--the main haul road, the crusher/storage area, and the paved highway near the entrance to the plant. A tenth hi-vol was located upwind of the quarry at one of the four fixed sites (for power).

Distances of approximately 25, 50, and 75 m were used where possible, but had to be adjusted in some sampling periods (at all three sources) because of physical obstructions. The air quality impacts would be expected to be much greater at these close distances, and therefore no longer equivalent to ambient concentrations. Sampling periods were 1 to 3 hours, depending on amount of source activity and visual inspection of filter loadings. The samplers were moved for each sampling period so they were directly downwind at the start of the test. To make the equipment portable, the General Metal Works H-2000 hi-vols were mounted on easy-to-assemble tripods and powered by 5 kw gasoline-engine generators.

The haul road and crusher/storage area operations, with some tripod-mounted hi-vols visible in the photos, are shown in Figure 5.



Site at 0.5 km south of quarry



Site at 0.7 km south of quarry

Figure 4. Photos of sampling sites.

Main haul road

Crusher/storage area

Figure 5. Sources sampled in short-term tests.

2.4 MONITORING ACTIVITY RATES AND METEOROLOGICAL CONDITIONS

The primary purpose of this study was to determine the impact of a typical stone quarry on particulate concentrations. However, several other variables (e.g., days since rain, traffic volumes on highway) may also affect particulate concentrations in the vicinity of a quarry. There was no systematic approach that could be used before the study to identify which of these variables were significant. Therefore, several variables which could possibly affect particulate concentrations were monitored.

These variables fell into two distinct categories--source-related and meteorological. The following are the variables that were monitored:

<u>Source-related</u>

Operating schedule and/or observed activities at batch plant, agricultural fields, and unpaved roads
Location of source activities
Daily crushed rock production in quarry
Daily loading onto customers' trucks
Moisture content of inactive storage piles
Traffic volume on unpaved road (traffic counts on highway discontinued after several broken hoses)
Street surface loading

<u>Meteorological</u>

Temperature
Relative humidity
Windspeed
Wind direction
Precipitation frequency and amount

The information collected on each variable is summarized in Table 1. Activity data were recorded on the data sheet shown in Figure 6. A few soil samples were taken on road surfaces during the study. Soil size distribution data used for reference throughout the study is presented in Appendix Table A-2.

Meteorological equipment specified in Table 1 was located at the farthest north sampling site. The wind sensors were located on a 10-meter tower to be consistent with NWS stations.

Another important variable was the dust control program at the quarry. As part of the quarry operator's participation in the study, he was requested to water all dust-producing operations during the periods shown in Figure 2 and only water under special situations (such as neighbor complaints) during the remainder of the study. The staggered 2-week control and no

TABLE 1. INDEPENDENT VARIABLES MONITORED AT QUARRY

Variable monitored	Measurement	Instrument	Measurement time	Relationship to TSP sample
Operating schedules at quarry and batch plant	Hours/day	Visual observation	Daily	Indication of emission variability
Observed activities	Activity level	Visual observation	Daily	Indicates emission sources
Location of activities	Operating equipment, spatial location	Visual observation	Daily	Indicates emission locations
Quarry production	Tons/day	Plant supervisor	Daily	Estimate of emission rate
Moisture content	Wet and dry weights of a sample	Drying oven, lab balance	Daily	Corresponds to that day's sample
Traffic volume	24-hour volume (2 way) on unpaved road	Tube counter with recorder	Continuous; 24-hour, same as TSP	TSP increases with volume
Surface loading	Qualitative: heavy, moderate, light	Visual observation	Daily	TSP increases with loading
Windspeed	24-hour av. speed, % >12 mph	Continuous recording	Continuous 24-hour, same as TSP	Concurrent periods
Wind direction	Hours per day sampler is downwind	Continuous recording	Continuous same as w.s.	Concurrent periods
Precipitation	Amount of rain per day	Recording rain gauge	Each day 24-hour	Many possible relationships
Temperature and r.h.	Temperature and r.h.	Hydrothermograph	Average of readings for each day	Related to that day's sample

Rain gauge Rain amt in reset

Hygrotherm ink ___ time set ___ paper ___

Wind instr ink ___ time set ___ paper ___

Wind forecast direction ________ reset directional controls ________
Barometric pressure, in. ________

Hi-vol	Filt #	Init flow	Final flow	Run. time	Meas conc	Net conc
1 DIR						
2 HV						
3 DIR						
4 SSI						
5 HV						
6 HV						
7 SSI						
8 DIR						
9 HV						
10 DIR						

Wet weight, g ________ Sample No. ______

Dry weight, g ________

Moisture wt, g ________ % ______

By ________________

Date mailed to K.C. ________

Traffic Data

	Paved Unpaved	Trackout:	
Start	________	light	______
End	________	med.	______
Count	________	heavy	______

Sampling eqpt. problems:

Production Data   Show location of activities on back of sheet

No. of haul truck loads ________
observation time, hr ________

No. of front end loaders working ________

Crushers operating 1 ______ hr ______
2 ______ hr ______
3 ______ hr ______

Aggregate shipped:
truckloads ________
tons ________

External Sources

Activity data	Location/process	Description	Duration
Batch plant			
Agriculture			
Unpaved roads			
Other			

Control Data
Visible plumes
yes _____ no _____
locations ________
duration ________

Water trucks operating
yes _____ no _____
time, hr _____ truckloads ____
passes in storage area ______
Passes on roads _____ locations ________

Spray bars on conveyors working
yes _____ no _____
No. hr ________

Wind erosion of barren surfaces
yes _____ no _____
locations ________
duration ________

Figure 6. Illinois quarry study daily checklist.

control periods were designed to randomize the occurrence of meteorological and process conditions between the control/no control subsets.

The amount of water applied per day could not be reliably monitored. However, control activities were reported on the data sheets and the watering schedule of Figure 2 was strictly adhered to. Watering was normally accomplished by hauling bucketsful in a front-end loader to the area where surface wetting was desired and then slowly dumping the bucket while moving the loader. Since this method generally applied more water on the surfaces covered than a water spray truck, normal procedure was to water each area only once per day. It was judged that this method resulted in lesser average control than more frequent (hourly or semi-hourly) applications with a water spray truck.

The crusher and conveyors had continuous water sprays that were actuated whenever this equipment was operating (except during specified no control periods during the testing).

2.5 QUALITY ASSURANCE PROCEDURES

Quality assurance procedures are a required element of all field studies. These procedures are necessary to insure the integrity of the study results and to allow others to use the data with confidence. The six main categories which a quality assurance program for fugitive particulate sampling must address are:

- Calibration of equipment
- Filter and impaction substrate selection and preparation
- Sampling procedures
- Sampling equipment maintenance
- Laboratory analysis procedures
- Calculations and data reporting

The study design report identified specific actions within each of these categories to be carried out during the field study. These actions, presented again in Table 2, were all implemented with the exception of the last two (send copy of field notes to office weekly and independent audit).

None of the single point flow-checks indicated units out of calibration. The 80 blank filters handled in the field and

TABLE 2. QUALITY ASSURANCE PROCEDURES

General activity	Specific check	Recommendation
Flow rate calibration	Multipoint calibration with orifices (hi vol)	At start of study, plus twice at scheduled maintenance
	Single point flow check	At middle of each month
Filter preparation	Visual inspection for tears and frayed edges	-
	Numbering of filters and identifications by sampler and sampling period	-
	Filter handling in clean environment	-
	Equilibration prior to weighing	24-h at 20 to 25°C and 40 to 50% humidity
Scheduled equipment maintenance	Motor brushes	Change every 400 running h
	Hi-vol gaskets	Check every calibration
Sampling procedures	Specified in study design	All procedures logged into field notebook, checked weekly
Laboratory analysis	Blank filters returned to lab	At least 5% of filters
	Reweighing of filters	At least 7%; within 3.0 mg or reweigh lot
	Acceptable resolution	1 mg for hi vol
Data handling	Calculation of concentrations and/or emission rates	Independent recalculation of 7% of values
	Separate data sheet for each sampling period completely filled out at end of test (1-week studies)	-
	One copy of field notes and data sent to office weekly	Original kept by field technician
Independent audit	Audit of flows, weights, equipment, and procedures by an independent group using their own equipment	Once during study if desired by IEPA or INR

returned to the lab unexposed had an average weight increase of 3.6 mg, only slightly more than the acceptable tolerance for reweighing of a filter. Only one out of about 170 duplicate weighings was outside the acceptable range of 3.0 mg difference.

SECTION 3

DATA ANALYSIS METHODOLOGY

Data were gathered in this field study under certain prespecified operating and dust control conditions so that average air pollutant concentrations under the different conditions could be compared for significant differences. The calculation of average concentrations for a data set is not a procedure that requires explanation. However, several independent variables beyond the control of this study may have affected concentrations unevenly during the different study periods. The effects of these variables were evaluated by the analytical technique of multiple linear regression. Also, a statistical test was used to determine whether the differences in average concentrations were significant.

Multiple linear regression and two tests for significance as applied in this study are explained below.

3.1 MULTIPLE LINEAR REGRESSION

This is a statistical technique for describing expected values of a dependent variable, in this case particulate concentrations, in terms of corresponding values of two or more other variables. It involves use of the method of least squares to determine a linear prediction equation from a set of simultaneously-obtained data points for all the variables. The equation is of the form:

$$\text{Partic conc} = B_1x_1 + B_2x_2 + \ldots + B_nx_n + \text{constant}$$

where x_1 to x_n = concurrent quantitative values for each of the independent variables

B_1 to B_n = corresponding coefficients

The coefficients are estimates of the rate of change in concentrations produced by each variable. They can be determined easily by use of a multiple linear regression (MLR) computer program or with a programmed calculator. Other outputs of the MLR program are:

1. A correlation matrix. It gives the simple correlation coefficients of all of the variables (dependent and independent) with one another. It is useful for identifying two interdependent variables (two variables that produce the same effect on concentrations), one of which should be eliminated from the analysis.

2. The multiple correlation coefficient (after addition of each independent variable to the equation). The square of the multiple correlation coefficient is the fraction of total variance in particulate concentrations that is accounted for by the variables in the equation at that point.

3. Partial correlation coefficient. This is the correlation between the dependent variable and one independent variable (e.g., x_3) after the influences of the other independent variables have been removed. It is different than the simple correlation coefficient, which ignores the variation caused by the other independent variables.

4. Residual coefficient of variability. This is the standard deviation of the concentrations predicted by the equation (with the sample data set) divided by the mean of the predicted concentrations, expressed as a percent. If a variable eliminates some sample variance, it will reduce the standard deviation and hence the relative coefficient of variability.

5. Significance of regression as a whole. This value is calculated from a F test by comparing the variance accounted for by the regression equation to the residual variance. A 0.05 significance level is a 1 in 20 chance of the correlation being due to random variation.

6. Significance of partial correlation coefficient. This value is derived from a F test of two variables with the data adjusted for all other variables. Variables that do not meet a prespecified significance level may be eliminated from the equation.

7. Constant in the equation.

The multiple correlation coefficient, unlike the simple correlation coefficient, is always positive and varies from 0 to 1.0. A value of zero indicates no correlation and 1.0 means that all sample points lie precisely on the regression plane. Because of random fluctuations in field data and inability to identify all the factors affecting air quality, the multiple coefficient is almost never zero even when there is no correlation and never 1.0 even when concentrations track known variables very closely. Therefore, it is important to test for statistical significance.

The form of MLR in the program used in this study was stepwise MLR. Variables are added to the equation in order of greatest increase in the multiple correlation coefficient, with concentrations then adjusted for that variable and regressed against the remaining variables again. The procedure can be ended by specifying a maximum number of variables or a minimum F value in the significance test.

In order to satisfy the requirement that the variables be quantitative, two were input as dummy variables with only two possible values. Poor control (no watering) was 0 and good control was entered as 1; southerly winds were assigned a 0 and northerly winds were 1.

A statistically significant regression relationship between independent variables and particulate concentrations is no indication that the independent variables cause the observed changes in concentration, as both may be caused by a neglected third variable.

3.2 SIGNIFICANCE OF A CORRELATION

The significance of multiple correlations are calculated internally by the MLR program. To determine whether a simple correlation coefficient is significant at the 0.05 level, the curve of confidence belts shown in Figure 7 can be used. The curve is entered with a known sample correlation coefficient on the x-axis. This x-value is marked vertically, and the distance between the two curves labeled with the appropriate sample size (n) is noted. If any portion of the vertical line between the two curves passes through 0 on the y-axis, the population correlation coefficient could be 0 so the sample correlation is not significant.

To determine whether a partial correlation coefficient is significant, n - k + 1 should be used in place of n for sample size (k + 1 is the number of variables).

3.3 SIGNIFICANT DIFFERENCES IN MEANS

The two-sided t-test is used to determine whether the average of one sample differs from that of another (e.g., periods with watering and no watering). The procedure for this test is as follows:

1. Select α, the significance level to be tested.

2. Look up $t_{1-\alpha/2}$ for $n = (n_A + n_B - 2)$ degrees of freedom in standard t distribution table.

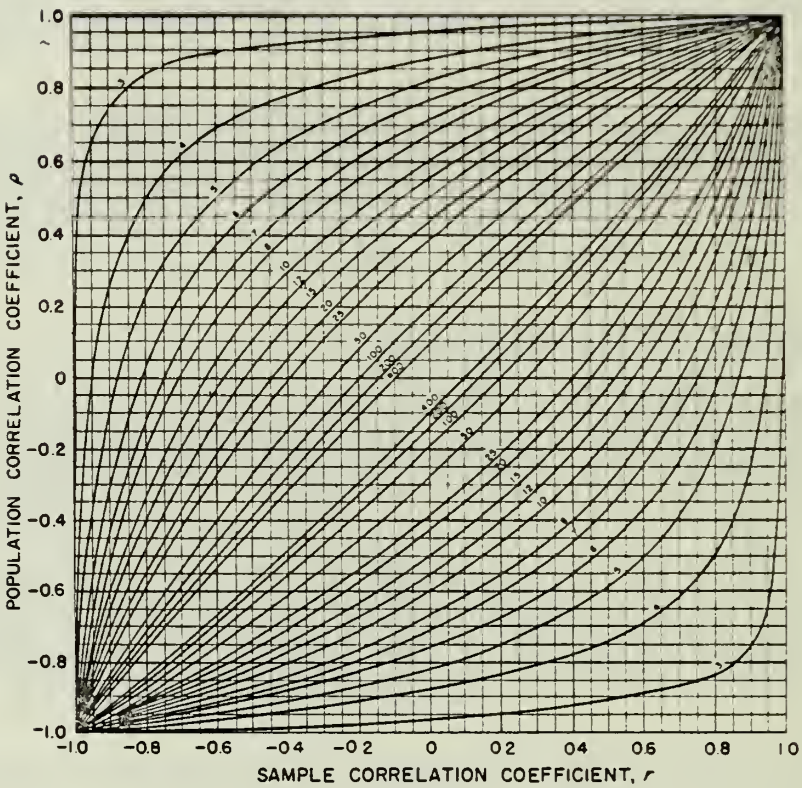


Figure 7. Confidence belts for correlation coefficients, 0.05 significance level.

Source: Crow, E. L., F. A. Davis, and M. W. Maxfield. Statistics Manual. New York, New York, Dover Publications. 1960.

3. Compute $\bar{x}_A$ and s_A^2, $\bar{x}_B$ and s_B^2 for the two data sets.

4. Compute $S_p = \sqrt{\dfrac{(n_A-1)s_A^2 + (n_B-1)s_B^2}{n}}$

5. Compute $u = t_{1-\alpha/2}\ s_p\sqrt{\dfrac{n_A + n_B}{n_A n_B}}$

6. If $\bar{x}_A - \bar{x}_B > u$, A and B differ with regard to their average performance; otherwise, there is no reason to believe they differ.

A 0.10 significance rather than 0.05 has been used in comparing means in this study because of the variability expected in measured concentrations.

SECTION 4

RESULTS OF FIXED NETWORK SAMPLING AT QUARRY

4.1 NET DOWNWIND CONCENTRATIONS

Daily sampling over the three month period produced a total of 74 data sets for use in estimating the impact of the quarry at downwind distances of 0.5 and 0.7 km. Each data set consisted of four upwind hi-vol measurements from which only a single upwind value was needed, 24-hour and directional concentrations at each of the two downwind distances, and upwind and downwind inhalable particulate (IP) concentrations. Prevailing wind direction (northerly or southerly) was decided by review of the continuous wind direction printout and running times on the directional hi-vol units. Raw data for the 74 days are presented in Appendix A, Table A-3.

The upwind concentration was determined from one of the two values recorded at the 0.7 km site because this location was more remote from the quarry and less susceptible to interferences during periods of variable winds. The concentration from the directional hi-vol, which should receive no contribution from the quarry even if the winds reversed, was used as upwind if it ran more than half the time during the day. If the directional ran less than half the time, it was possibly subject to larger measurement errors and not necessarily representative of the full day's air quality so the 24-hour concentration at the 0.7 km upwind site was used as the upwind value for that day.

This procedure for determining the particulate concentration in the incoming air produced the lowest of the four upwind readings on 43 of the 74 days. The procedure is based on the premise that during most 24-hour periods close-in receptors in all directions from a large ground-level source receive some contribution from that source; it is directed at selecting the sampler with the least impact. Although it resulted in the lowest value being selected on most occasions, this is thought to indicate impact from the quarry on the other samplers rather than a negative bias for the procedure. The geometric mean of the 74 wind values was 64.5 $\mu g/m^3$, still above background levels in this rural area of Illinois.

The upwind value was subtracted from each of the four downwind concentrations for the day to get net concentrations. These net concentrations by day, sorted into three subsets composed of samples taken during periods of poor dust control (no watering), good dust control (frequent watering), and no activity, are shown in Table 3. If net concentrations were negative, a value of 0 was substituted in subsequent data analysis.

The average impacts during the times when samplers were in the plume from the quarry (directional samplers) were 40 to 63 $\mu g/m^3$. Over 24-hour periods the impact averaged 11 to 33 $\mu g/m^3$. The relatively high standard deviations indicate large daily variations in impact as would be expected over the full range of quarry operations (no activity to full production) and meteorological conditions.

The effect of watering for dust control could not be detected in the difference in net concentrations between the poor control (no watering) and good control (frequent watering) subsets. The directional units showed reductions in impact of 13 and 21 percent at distances of 0.5 and 0.7 km, but the 24-hour readings had apparent increases of 16 and 12 percent during the days with watering. None of these differences were significant at the 90 percent confidence level--this would require reductions or increases of 55 to 62 percent for nonpaired data sets of sample size 22 to 27 with the large standard deviations shown in Table 3. Overall, the poor versus good control data subsets had surprisingly small differences considering the scatter in the day-to-day concentrations.

The quarry continued to have a substantial impact on days classified as having no operations--Saturdays, Sundays, and holidays. The directional hi-vols indicated net concentrations of 42 $\mu g/m^3$ and the 24-hour hi-vols had impacts of 15 and 11 $\mu g/m^3$ at the two distances from the quarry. The latter two concentrations are significantly lower (at the 90 percent confidence level) than those on days with operations. It should be noted that there was loading of customers' trucks on Saturdays in June and July. Also, wind erosion from the storage piles and other exposed areas would continue on days with no operations, and the unpaved road south of the quarry had traffic on weekends and possibly contributed to concentrations on days with winds from the north. The impact of the unpaved road is analyzed in detail later in this section.

Comparison of the impacts for periods with normal operations and with no operations leads to the conclusion that quarrying, haul trucks, crushers, etc. have an incremental effect of about 15 $\mu g/m^3$ at 0.5 km and about 4 $\mu g/m^3$ at 0.7 km. This is equal to or less than the apparent impact from wind erosion during periods with no or only limited operations.

TABLE 3. NET DOWNWIND CONCENTRATIONS SEGREGATED BY LEVEL OF DUST CONTROL

Net downwind concentration, μg/m³														
Poor control (no watering)					Good control (frequent watering)					Quarry not operating				
Date	.5 km dir	.7 km dir	.5 km 24-h	.7 km 24-h	Date	.5 km dir	.7 km dir	.5 km 24-h	.7 km 24-h	Date	.5 km dir	.7 km dir	.5 km 24-h	.7 km 24-h
5-07	73	201	<0	11	5-27	42	39	<0	<0	5-10	37	20	20	42
5-08	161	135	<0	<0	5-28	61	64	10	<0	5-16/	48	52	<0	<0
5-09	23	17	9	20	5-29	20	<0	15	20	17/18				
5-12	248[a]	234[a]	36	25	5-30	103	32	79	75	5-23/	15	21	10	15
5-13/14	62	32	34	0	6-02	4	4	6	4	24/25				
5-15	1	1	<0	4	6-03	13	7	<0	0	5-26	60	66	33	37
5-19	<0	<0	3	11	6-04	20	10	4	<0	5-31	63	60	<0	<0
5-20	n.d.	n.d.	48	49	6-05	20	22	3	8	6-01	156[a]	163[a]	14	22
5-21	n.d.	n.d.	13	24	6-06	n.d.	16	n.d.	9	6-07	n.d.	n.d.	21	10
5-22	38	<0	<0	1	6-23	<0	<0	<0	<0	6-08	24	1	24	0
6-09	n.d.	n.d.	3	<0	6-24	10	0	4	61	6-14	5	<0	<0	<0
6-10	65	15	21	9	6-25	n.d.	23	3	<0	6-15	1	<0	3	4
6-11	26	36	12	30	6-26	13	16	0	<0	6-21	22	15	5	2
6-12	1	12	11	6	6-27	124	n.d.	8	n.d.	6-22	<0	<0	18	<0
6-13	52	37	34	27	6-30	n.d.	n.d.	79	15	6-28	67	159	23	10
6-16	4	1	6	4	7-01	<0	123	<0	<0	6-29	n.d.	n.d.	21	8
6-17	69	44	29	7	7-03	186	77	167	35	7-07	30	<0	23	25
6-18	28	17	15	5	7-21	n.d.	n.d.	45	26	7-08	8	19	6	7
6-19	121	30	45	10	7-22	108	55	92	46	7-12	n.d.	n.d.	3	<0
6-20	27	20	17	5	7-23	12	<0	<0	<0	7-13	38	14	n.d.	<0
7-09	23	14	<0	<0	7-24	14	1	2	<0	7-19	n.d.	n.d.	9	0
7-11	91	92	6	0	7-25	36	37	16	9	7-20	n.d.	n.d.	32	19
7-14	47	31	41	10	7-28	158[a]	148[a]	186	61	7-26	94	93	41	35
7-15	n.d.	n.d.	190	90	7-29	137[a]	152[a]	39	14					
7-16	170	138	35	20	7-30	62	35	<0	7					
7-17	n.d.	n.d.	119	0	7-31	74	55	61	18					
7-18	63	<0	37	24										
av	63.3	50.3	28.3	14.5		55.3	39.8	32.7	16.3		41.8	42.7	15.3	11.2
std dev	(62.8)	(67.0)	(40.8)	(19.5)		(56.4)	(46.0)	(51.9)	(22.2)		(40.6)	(53.9)	(12.2)	(13.7)
n	22	22	27	27		22	23	25	25		16	16	20	21

[a] Directional units ran less than 10 percent of the time on these days. Consequently, passive loading

The impact of the quarry dropped rather quickly with distance from 0.5 to 0.7 km--15 μg/m^3 when there were operations and 4 μg/m^3 when there were no operations. It is not possible to extrapolate these observed rates of decrease further away from the source because the reductions are caused by plume dispersion and particle deposition, which change at different rates as a function of distance.

The directional hi-vol concentrations in Table 3 did not appear to bear a consistent relationship with the 24-hour concentrations for the same time periods. However, when the net directional concentrations were multiplied by the percent of possible time that they ran, the time-adjusted values in general compared quite well with corresponding 24-hour net concentrations. On 25 days, this percentage was about the same as the ratio of 24-hour to directional concentrations; on only 10 days did it make the comparisons worse. This indirectly indicates that no large particulate impacts were present near the quarry in other wind directions. (Time-adjusted values were not used in any subsequent analyses.)

In evaluating the directional hi-vol concentrations, it was noted that the two directional controls did not consistently operate the same amount of time each day. These running times were then compared with the percent of time that the on-site continuous-recording instrument showed that wind direction was from the appropriate quadrant. The times for each day, summarized in Table 4, reveal that some of the wide fluctuations in concentrations from the directional hi-vols may be attributed to problems with the directional control units.

On 12 days out of the 62 with directional data, the percentages of running time on the two directional units differed substantially. This could have been due to extremely localized wind effects or to equipment malfunction. On 12 other days, the two directional units were in agreement but they differed from the wind direction recorder on-site. If all 24 of these days were eliminated from the data set, the resulting average net concentrations by subset would be:

Control	Dist, km	Av. net conc., μg/m^3	No. of samples
Poor	0.5	65.1	15
	0.7	61.2	15
Good	0.5	53.1	13
	0.7	41.7	13
No operation	0.5	39.7	10
	0.7	49.0	10

TABLE 4. RUNNING TIMES FOR DIRECTIONAL HI-VOLS

Date	Running time, % of day			Date	Running time, % of day		
	South unit	North unit	Wind dir in quadrant		South unit	North unit	Wind dir in quadrant
May 10	100	69	87	June 21	21	9	7
11	n.d.	26	17	22	75	80	86
12	3	3	3	23	26	36	37
13,14	0	31	29	24	37	0	28
15	42	28	35	25	24	45	48
16-18	4	7	5	26	27	58	n.d.
19	24	21	0	27	8	19	10
20	0	0	0	28	28	27	43
21	0	2	14	29	3	0	0
22	2	15	7	30	3	0	26
23-25	8	25	n.d.				
26	51	62	67	July 1	43	37	41
27	23	28	0	3	89	34	94
28	54	63	63	7	78	95	69
29	94	90	79	8	50	53	43
30	90	88	90	9	44	31	43
31	28	35	22	11	6	n.d.	3
				12	42	n.d.	21
June 1	17	4	60	13	15	13	66
2	44	94	73	14	99	99	68
3	20	23	6	16	9	15	13
4	0	0	5	18	42	52	54
5	68	81	68	19	n.d.	3	0
6	62	69	55	22	60	78	46
7	0	0	1	23	61	63	56
8	31	59	50	24	22	47	10
9	0	0	3	25	61	52	45
10	63	78	49	26	10	10	19
11	21	24	38	28	4	1	1
12	83	86	96	29	6	6	33
13	67	89	92	30	16	11	16
14	64	81	66	31	49	61	61
15	48	52	88				
16	94	95	93				
17	22	38	63				
18	58	67	73				
19	22	25	47				
20	24	26	21				

There is no way of confirming that the two directional units ran at the same times if their total running times were in agreement. Also, the times of day that each ran (when the quarry was in operation or shut down) could not be determined from available records.

4.2 EFFECT OF SOURCE-RELATED AND METEOROLOGICAL VARIABLES ON CONCENTRATIONS

The effect of independent variables on (net) particulate concentrations was assessed by stepwise multiple linear regression analysis. The technique and its application in this study were explained in Section 3. The purpose of this analysis was to identify the independent variables that were linked most closely with particulate concentrations. Variables selected for inclusion in the analysis were:

<u>Source-related</u>

- Quarry production, tons/day
- Amount of crushed rock shipped (loaded out in trucks), tons/day
- Traffic volume on unpaved road south of quarry, veh/day
- Watering, yes/no
- Batch plant operation, graded from light to heavy operations/ emissions

<u>Meteorological</u>

- Surface moisture content, percent
- Days since rain
- Average windspeed, mph
- Winds greater than 12 mph, percent of day
- Prevailing wind direction for day (and setting of the directional control units), northerly/southerly

The full data set input to the program is shown in Appendix A, Table A-4. Since control measures and production rates were variables being evaluated, all the data had to be considered as a single data set (rather than the three subsets discussed in the preceding section).

Other data that were collected, such as temperature and relatively humidity, were either preliminarily evaluated by simple linear regression and found to not be significant or reserved for backup use in the event that the primary variables failed to explain the measured particulate concentrations. Some of the variables listed above could have been interrelated. This was checked in the correlation matrices produced by the MLR program. None were found to have intercorrelations greater than

0.6, so there was no need to drop any variables from the analysis.

The simple correlation coefficients for the individual independent variables with each of the four downwind hi-vol concentrations (for 74 data pairs) are shown in Table 5. Corresponding values were generated with IP concentrations for the 42 days on which these samples were collected, from June 13 through July 31. Correlations with IP were observed to be generally much higher. Under the premise that the higher correlations were related to the different sample set rather than the substitution of IP for suspended particulate, the correlations in Table 5 were all rerun with just data from June 13 through July 31. In 35 out of 40 cases, correlation coefficients increased with the data from the second half of the study instead of the full study. These correlations, along with the IP correlations, are shown in Table 6. Two other partial data sets--May 26 through July 31 and June 4 through July 31--were also screened, but both gave correlations intermediate between those in Table 5 and those in Table 6.

For the full data from the study (Table 5), none of the variables individually affected net particulate concentrations very strongly. Only three correlations in the table were significant at the 0.05 level (95 percent confidence level). By comparison, eight of the correlations in Table 6 were significant at the 0.05 level. The improved relationship between identified independent variables and particulate concentrations during the second half of the study could be attributed to fewer problems with the sampling equipment or fewer rainstorms, but there is no conclusive means of establishing the true reason.

The only variable that was repeatedly significant at the 0.05 level was the amount of crushed rock shipped per day. This is an indication that the storage and loadout area had more impact than the pit area (represented by quarry production) on particulate air quality.

Very few meteorological variables produced high correlations. This is difficult to explain in view of the correlation with meteorological variables during the short-term tests, as reported in Section 5. Upwind or background concentrations were compared with days since rain by simple linear regression (outside the MLR program) and found to have a correlation coefficient of only 0.081.

The MLR analysis results are summarized in Table 7. No further variables were added to a sequence after the overall significance of the multiple regression equation became worse and the significance of the last variable added exceeded 0.30. The multiple correlations (R) did not explain much of the sample

TABLE 5. SIMPLE CORRELATIONS WITH FULL DATA SET

Independent variable	Correlation coefficient with dependent variable[a]			
	0.5 km dir	0.7 km dir	0.5 km 24-h	1.0 km 24-h
Source-related				
Quarry production, ton	0.13	-0.02	0.16	0.05
Amt shipped, ton	0.20	0.16	0.28	0.18
Traffic vol on unpaved road, veh/day	0.17	0.01	0.08	-0.17
Watering, yes/no	0.08	0.08	0.06	0.03
Meteorological				
Surface moisture, %	-0.14	-0.07	-0.26	-0.02
Days since rain	-0.02	-0.06	0.11	-0.04
Av windspeed, mph	0.07	0.10	0.09	0.09
Winds >12 mph, %	0.01	0.06	0.03	0.06
Prevailing wind dir, N/S	0.24	-0.03	0.30	-0.13

TABLE 6. SIMPLE CORRELATIONS WITH JUNE 13 TO JULY 31 DATA SET

Independent variable	Correlation coefficient with dependent variable[b]				
	0.5 km dir	0.7 km dir	0.5 km 24-h	0.7 km 24-h	0.5 km IP
Source-related					
Quarry production, ton	0.16	0.06	0.27	-0.02	-0.12
Amt shipped, ton	0.37	0.36	0.40	0.07	0.54
Traffic vol on unpaved road, veh/day	0.39	0.12	0.22	-0.29[c]	0.31
Watering, yes/no	0.20	0.29	0.04	0.37	0.22
Batch plant operation	0.31	0.17	0.19	0.24	0.08
Meteorological					
Surface moisture, %	-0.35	-0.24	-0.19	-0.17	-0.03
Days since rain	-0.05	-0.13	-0.02	-0.07	0.05
Av windspeed, mph	0.07	0.06	0.10	-0.07	0.08
Winds >12 mph, %	0.01	0.07	-0.04	0.08	0.02
Prevailing wind dir, N/S	0.42	0.16	0.30	-0.05	0.17

[a] Correlation coefficients at 0.05 level for directional data are significant if they are ≥0.26, for 24-h data if they are ≥0.24.

[b] Correlation coefficients at 0.05 level for directional data are significant if they are ≥0.34, for 24-h data if they are ≥0.31, for IP data if they are ≥0.32.

[c] Should be a positive correlation.

TABLE 7. STEPWISE MULTIPLE REGRESSION RESULTS

Dependent variable	Data set	Independent variables in order of importance	Multiple correlation coefficient	Significance of variable	Overall significance
0.5 km dir	5/7 to 7/31	Prevailing wind dir	0.24	0.062	0.062
		Amt shipped, ton	0.32	0.094	0.043
		Traffic volume	0.34	0.287	0.061
0.7 km dir	5/7 to 7/31	Amt shipped, ton	0.16	0.212	0.212
		Windspeed, mph	0.20	0.375	0.310
0.5 km 24-hour	5/7 to 7/31	Prevailing wind dir	0.30	0.009	0.009
		Amt shipped, ton	0.42	0.008	0.001
		Windspeed, mph	0.44	0.209	0.002
		Surface moisture	0.46	0.193	0.002
		Quarry production	0.47	0.525	0.004
0.7 km 24-hour	5/7 to 7/31	Amt shipped, ton	0.18	0.121	0.121
		Prevailing wind dir	0.22	0.271	0.165
		Windspeed, mph	0.25	0.335	0.211
0.5 km dir	6/13 to 7/31	Prevailing wind dir	0.42	0.010	0.010
		Traffic volume	0.57	0.012	0.002
		Watering yes/no	0.64	0.047	0.001
		Amt shipped, ton	0.67	0.133	0.001
		Moisture content	0.68	0.389	0.002
0.7 km dir	6/13 to 7/31	Amt shipped, ton	0.36	0.032	0.032
		Watering, yes/no	0.41	0.205	0.046
		Prevailing wind dir	0.45	0.280	0.063
0.5 km 24-hour	6/13 to 7/31	Amt shipped, ton	0.40	0.045	0.045
		Prevailing wind dir	0.53	0.058	0.022
		Surface moisture	0.58	0.202	0.028
		Days since rain	0.60	0.323	0.041
		Watering, yes/no	0.62	0.448	0.066
		Windspeed	0.66	0.230	0.069
		Batch plant op	0.66	0.640	0.113
0.7 km 24-hour	6/13 to 7/31	Watering, yes/no	0.37	0.026	0.026
		Traffic volume	0.45	0.101	0.022
		Batch plant op	0.49	0.256	0.032
0.5 km IP	6/13 to 7/31	Amt shipped, ton	0.54	0.004	0.004
		Traffic volume	0.63	0.071	0.003
		Prevailing wind dir	0.67	0.143	0.004
		Quarry production	0.69	0.255	0.006
		Surface moisture	0.72	0.240	0.008
		Days since rain	0.74	0.345	0.013

variances in the May 7 through July 31 data sets (the portion of total variance explained = R^2). At only one of the four samplers (0.5 km 24-hour) did the multiple regression equation have a better overall significance than that of the first variable. The smaller data set from the second half of the study produced much higher multiple correlations--0.45 to 0.74, or 20 to 55 percent of the variance explained.

The amount of crushed rock shipped per day and prevailing wind direction were two of the most important variables in almost every MLR run. The implications of the former variable being significant were discussed above. Prevailing wind direction could be a significant variable because of differences in effective source-receptor distances in the two directions or because of impact from the unpaved road with winds from one of the two directions. Correlation coefficients for prevailing wind direction and traffic volume on the unpaved road tended to move together from run to run in Tables 5 and 6, and were always much higher at the 0.5 km distance than at 0.7 km. The impact of the unpaved road is evaluated further in the following paragraphs.

IP had the highest multiple correlation of any of the particulate measurements. Small particle concentrations are less affected by local entrainment, deposition, and other confounding factors, so they would be expected to demonstrate a more consistent relationship with source-related and meteorological variables.

After the MLR analysis indicated that the unpaved road might be adding a substantial concentration to the samplers south of the quarry on days with wind from the north (and thereby increasing the apparent impact from the quarry), a comparison of average concentrations with winds from each of the two directions was made. The results of this comparison are presented in Table 8.

The data in total did not show a distinct difference in concentration as a function of which samplers were downwind. Some of the sampler pairs had wide differences, which may explain why prevailing wind direction (northerly or southerly) was a significant variable in many of the MLR analyses. On the basis of the four suspended particulate sampler pairs (first four lines of table), it could by hypothesized that the unpaved road had an impact on the 0.5 km samplers close to the road (about 50 m) but not on the 0.7 km ones further away (about 250 m). However, the IP sampler located at the 0.5 km site did not substantiate this hypothesis.

Dividing the data into subsets for sampling periods with poor control, good control, and no operations did not add any additional insights. If the unpaved road did contribute to the samplers south of the quarry, it appears that its impact was very inconsistent. Also, relatively few of the sampling days had

TABLE 8. COMPARISON OF AVERAGE NET CONCENTRATIONS AT NORTH AND SOUTH SAMPLERS

Samplers being compared	No. of days winds from S	No. of days winds from N	Av net conc at N sampler with winds from S, $\mu g/m^3$	Av net conc at S sampler with winds from N, $\mu g/m^3$	Increase possibly attributable to unpaved road, $\mu g/m^3$	Increase %
0.5 km dir	43	17	53.0	58.6	5.6	10.6
0.7 km dir	44	17	48.2	34.4	-13.8	-28.6
0.5 km 24-hour	49	23	18.8	41.9	23.1	122.9
0.7 km 24-hour	49	24	14.1	14.5	0.4	2.8
0.5 km IP	26	17	23.3	13.8	-9.5	-40.8
All except IP samples	185	81	32.5	35.7	3.2	9.8

Note: Data for this table were obtained directly from Table 3 by segregating values in the 0.5 km dir, 0.7 km dir, 0.5 km 24-h, and 0.7 km 24-hour columns into days with winds from the south and days with winds from the north (see Table A-3 for wind directions by day). Similarly, IP concentrations on Line 5 are a segregation, by wind direction of the net downwind IP concentrations shown in Table 9.

winds from the north (30 percent), so a moderate impact on these days would still not distort the overall results.

Another potential interference in the area, the asphalt batch plant, was included in the MLR analysis. The plant had wide variations in operation over the period of the study, but these variations did not correlate well with any of the measured concentrations at the quarry. It should be noted that increasing batch plant activity always had a positive correlation with net concentrations, but it was never high enough to be significant at the 0.05 level. The data which constitute this analysis are all presented in Tables 6 and 7.

Tilling of nearby fields could also have interfered with measurements at the sites. However, very little activity in the fields was observed during the three months, and days with tractors in nearby fields did not result in noticably higher concentrations at the closest samplers.

4.3 SIZE DISTRIBUTION DATA

The inhalable particulate concentrations for 43 days are shown in Table 9. Each of these IP samples was obtained simultaneously with a collocated suspended particulate (TSP) sample. The ratio of IP to TSP for each sample is also presented in Table 9. The average ratios were 0.71 and 0.85 at the sites south and north of the quarry, both higher than the ratio of 0.65 reported for several EPA monitoring sites (mainly urban) that have been testing the size-selective hi-vol.[3] This indicates that the particles at a distance of 0.5 km from the quarry have a relatively small size distribution and should remain suspended for extended periods, a surprising finding for fugitive dust from quarries. Possibly by a distance of 0.5 km most of the large particles generated by quarry operations have already settled out.

The net IP concentrations for each day are also shown in Table 9. They were calculated by subtracting the upwind IP concentration from the downwind IP concentration for the same day. The net IP concentrations were segregated into three subsets--poor dust control (no watering), good dust control (frequent watering), and no quarry activity--just as the TSP data were in Table 3. The average concentrations for each subset (when negative values were included as 0 $\mu g/m^3$ impact) were:

	Av, $\mu g/m^3$	Std. dev, $\mu g/m^3$	n
Poor control (no watering)	24.5	27.4	13
Good control (frequent watering)	21.5	24.1	17
Quarry not operating	12.3	16.9	13

TABLE 9. INHALABLE PARTICULATE (<15 μm) CONCENTRATIONS

Date	Dust control in effect[a]	IP concentration, μg/m³		Prevailing wind dir/ % of day within 45° of S or N	Net downwind conc, μg/m³ (see columns 2 and 3)	Fraction of TSP (24-h at 0.5 km)	
		At south sampler	At north sampler			At south sampler	At north sampler
6-13	P	84	131	S (92)	47	1.00	1.07
6-14	N	72	69	S (66)	<0 (-3)	0.75	0.70
6-15	N	35	42	N (88)	<0 (-7)	0.74	0.91
6-16	P	28	27	N (93)	1	0.70	0.79
6-17	P	35	48	S (63)	13	0.73	0.62
6-18	P	n.d.	n.d.				
6-19	P	65	73	N (47)	<0 (-8)	0.49	0.91
6-20	P	30	32	N (21)	<0 (-2)	0.61	n.d.
6-21	N	42	56	S (7)[b]	14[b]	0.72	0.78
6-22	N	0	59	S (86)	59	n.d.	0.68
6-23	G	56	58	S (37)	2	0.60	0.95
6-24	G	58	56	S (28)	<0 (-2)	1.00	0.92
6-25	G	55	37	S (48)	<0 (-18)	n.d.	0.62
6-26	G	79	88	S (n.d.)	9	0.91	0.97
6-27	G	117	117	N (n.d.)	0	n.d.	0.95
6-28	N	45	66	S (43)	21	0.54	0.59
6-29	N	48	18	N (85)	30	0.68	0.36
6-30	G	59	47	N (26)	12	0.49	n.d.
7-01	G	0	62	S (41)	62	n.d.	n.d.
7-03	G	122	67	N (94)	55	0.50	0.87
7-07	N	78	94	S (69)	16	0.38	0.82
7-08	N	77	73	S (43)	<0 (-4)	0.78	0.86
7-09	P	61	57	N (43)	4	1.33	0.81
7-10	P	58	57	S (38)	<0 (-1)	n.d.	n.d.
7-11	P	60	129	S (47)	69	0.82	1.52
7-12	N	66	70	S (49)	4	0.82	0.89
7-13	N	42	35	N (66)	7	n.d.	0.90
7-14	P	68	103	S (68)	35	0.79	0.74
7-15	P	90	172	S (65)	82	0.69	0.61
7-16	P	67	89	S (48)	22	0.51	0.74
7-17	P	93	60	N (47)	33	0.55	0.74
7-18	P	51	64	S (54)	13	0.61	0.76
7-19	N	76	80	S (65)	4	0.84	0.99
7-20	N	84	86	N (40)	<0 (-2)	0.80	1.18
7-21	G	34	57	S (52)	23	0.58	0.70
7-22	G	97	67	N (46)	30	0.57	0.87
7-23	G	51	59	N (56)	<0 (-8)	0.91	0.98
7-24	G	41	48	N (10)[b]	<0[b] (-7)	0.69	0.77
7-25	G	47	65	S (45)	18	0.90	0.95
7-26	N	76	81	N (49)	<0 (-5)	0.88	1.01
7-28	G	145	82	N (1)[b]	63[b]	0.60	0.67
7-29	G	29	90	S (33)	61	0.14	0.82
7-30	G	49	56	S (16)	7	0.75	1.27
7-31	G	76	100	S (61)	24	0.81	0.69
Arith mean		61.5	70.4		19.5	0.71	0.85
std dev		28.7	29.4		23.4	0.21	0.20
n		43	43		43	37	39

[a] P = poor control (no watering).
G = good control (frequent watering).
N = quarry not operating.

[b] Due to prevailing E/W winds on these days, the indicated net impacts may not have been from the quarry.

These impacts were very similar to those for TSP: 88, 80, and 84 percent of the TSP concentrations, respectively. Watering did not appear to have a different effect on small particles than on total particulate. A high percentage of the collected material downwind was less than 15 μm diameter during periods with no activity as well as during normal quarry operation.

In summary, quarries were definitely shown to be a source of small atmospheric particles because of the high IP/TSP ratios and the average net downwind impact of 19.5 $\mu g/m^3$ of particles less than 15 μm diameter. These small particles appeared to be emitted by production-related and wind erosion sources alike (they occurred at high levels on production days but also on days when the quarry was not in operation), and responded much the same as TSP to dust control measures at the quarry.

SECTION 5

RESULTS OF SHORT-TERM SAMPLING

5.1 TEST CONDITIONS

The short-term sampling was done for periods of one to three hours per test downwind from three different sources--the main haul road, the crusher/storage area, and the paved highway near the entrance to the quarry. This simultaneous sampling was designed specifically to permit direct comparison of the relative air quality impacts of these three major sources at the quarry. The crusher could not be evaluated separately from the storage or stockpile area because of their proximity.

The same three sources were compared in all 17 of the short-term test periods, although the samplers were placed in different locations from test to test so that they were always downwind of the sources. Selection of sources to be tested was based on visual observation and recommendations by all study participants; specific sampling locations were determined by PEDCo. A fourth major source, an asphalt batch plant and associated operations located southwest of the quarry, was scheduled for inclusion in the short-term sampling but was not operating during most of the three weeks of such sampling.

In accordance with the study design, hi-vol samplers were placed at three downwind distances from each source to allow multiple comparisons and to include distance from the source as a variable in the analysis. All downwind distances were relatively small so that interferences from other sources at the quarry could be minimized. The three distances could not be kept constant for all tests because of physical obstructions in some downwind directions, but an effort was made to keep the distances consistent for all three sources during any one test (again, so that measured impacts would be directly comparable). The closest samplers were 17 to 27 m (55 to 90 ft), and the back samplers were generally 57 to 82 m (190-270 ft). A single upwind hi-vol was employed for each test, making a total of 10 samplers in use.

The samplers were set up in six different alignments during the 17 tests: 7 times to the NE, 5 times to the NW, twice to the SW, and once each to the W, SSW, and N. The length of a sampling period was determined primarily by the amount of activity on the

haul roads and in the crusher area. If activity was heavy, one hour of sampling provided sufficient loading on the filters; if activity was light, as much as three hours was required.

5.2 TEST RESULTS

Net particulate concentrations downwind of the three sources for each of the 17 sampling periods are shown in Table 10. Sources with the highest and lowest impact for each test are noted. Average net concentrations by source are presented in Table 11.

The crusher/storage area had the greatest impact on particulate concentrations based on number of sampling periods with highest impact (11 out of 17) or on average net concentration at the three downwind distances. The haul road had the second highest impact, based on either its rankings in individual tests or its average concentrations. However, net concentrations decreased more rapidly with distance from the haul road than they did from the other two sources, leading to speculation that haul road emissions have larger size particles and therefore a smaller range of influence.

The paved highway at the entrance to the quarry produced surprisingly high downwind concentrations, although the impact was the least of the three sources sampled. Average concentrations downwind of the paved road were higher than they were downwind of the haul road when the latter was being watered for dust suppression (the final seven short-term tests). Also, concentrations were slightly higher at the back paved road sampler than at the back haul road sampler under all test conditions because of the aforementioned rapid decrease in concentrations away from haul roads.

5.3 EVALUATION OF SHORT-TERM SAMPLING DATA

The data were analyzed by simple linear regression to identify significant independent variables affecting the downwind concentrations. In particular, traffic volumes, surface moisture content, days since rain and windspeed were evaluated as potentially important variables. As indicated in the correlation matrix of Table 12, only one of the four activity parameters monitored proved to be significant at the 95 percent confidence level. In other words, the downwind concentrations measured in different tests were not closely related to the number of vehicles passing the samplers in those tests. Because of this finding, no attempt was made to normalize the concentrations for each test to average activity levels before ranking the impacts of the three sources.

TABLE 10. CONCENTRATIONS DOWNWIND OF SOURCES DURING SIMULTANEOUS SAMPLING

Test	Date	Upwind conc., $\mu g/m^3$	Net concentrations at three downwind samplers, $\mu g/m^3$ (in order of increasing distance from source) Haul road			Paved road			Crusher area		
No watering of sources											
1	6-11	107	534	24	93	51	74	57 LO	1024	1170	258 HI
2	6-11	118	1484	<0[a]	391 HI	39	78	84 LO	b	b	b
3	6-12	0	2808	1819	348	372	418	0 LO	3155	2093	1621 HI
4	6-12	69	1090	522	254 LO	631	687	684	4791	2358	2800 HI
5	6-13	0	5154	2825	360 HI	0	388	423 LO	1212	1259	1208
6	6-13	144	2668	1094	<0[a]	83	90	<0[a] LO	2707	849	1367 HI
7	6-16	63	4370	1039	2136 HI	980	738	557 LO	1517	1255	950
8	6-17	78	1342	274	243 LO	1152	882	1411	3150	1059	1152 HI
9	6-17	41	2126	938	538 LO	1060	1186	1565	1701	1143	1191 HI
10	6-18	66	3136	1004	695 HI	79	97	56	1566	764	970
Watering of haul roads and crusher area											
11	6-24	66	604	218	152	56	220	259 LO	763	597	223 HI
12	6-24	56	264	<0[a]	85 LO	742	419	332	1724	1600	662 HI
13	6-25	86	134	52	35 LO	411	228	153	1442	591	221 HI
14	6-25	76	502	188	273	326	224	141 LO	832	402	276 HI
15	6-25	73	506	205	159	276	128	87 LO	812	351	190 HI
16	6-26	116	708	359	b LO	1882	948	b HI	808	649	476
17	6-26	13	1126	565	417	1190	732	464 HI	568	400	359 LO

[a] When the upwind concentration was subtracted from the measured downwind concentration, a net value slightly less than zero resulted. For quantitative analyses, zero was substituted for the negative value.

[b] No sample.

Note: Measured concentrations can be obtained by adding the upwind concentration for a test to any of the net concentrations shown in this table.

TABLE 11. IMPACTS FROM SPECIFIC QUARRY OPERATIONS

Tests	Approx. dist., ft	No. tests	Av. net conc., μg/m³	Range of impacts,[a] μg/m³
Haul road, all	55- 90	17	1678.7	246-4370
	120-180	17	654.5	0-1819
	220-270	17	374.4	35- 695
Haul road, uncontrolled	55- 90	10	2471.2	1090-4370
	120-180	10	953.9	24-1819
	220-270	10	505.8	93- 695
Haul road, controlled	55	7	546.6	246- 708
	120	7	226.7	52- 359
	220	7	186.8	85- 273
Paved road near quarry entrance	60- 90	17	548.8	39-1190
	120-180	17	443.4	78- 948
	200-270	17	369.0	0-1411
Crusher area, all	50- 90	16	1735.8	763-3155
	110-180	21[b]	1084.1	359-2358
	190-260	11[b]	699.8	221-1208
Crusher area, uncontrolled	50- 90	9	2313.7	1212-3155
	110-180	12	1445.1	849-2358
	190-260	6	1021.0	258-1367[c]
Crusher area, controlled	50- 65	7	992.7	763-1442
	120-170	9	602.8	359- 649
	200	5	314.4	190- 662[c]

[a] Second lowest and second highest concentrations reported for each series of tests, except as noted.

[b] For some tests, the furthest samplers were located less than 180 ft from the crushers because of physical constraints. These third-row sampler readings have been grouped with second-row sampler readings taken at similar distances.

[c] Because of the small number of tests in this category, the lowest and highest net concentrations rather than second lowest and second highest are shown.

TABLE 12. CORRELATION MATRIX OF NET DOWNWIND CONCENTRATIONS AND SPECIFIED INDEPENDENT VARIABLES

Activity parameter or meteorological variable	Correlation coefficient, r								
	Haul road			Paved road			Crusher area		
	Closest	Middle	Back	Closest	Middle	Back	Closest	Middle	Back
Haul truck volume	0.20	0.19	0.15						
Total traffic volume				-0.15	-0.10	-0.14			
Eqpt. in crusher area							0.57[a]	0.48	0.51[a]
Trucks loaded							-0.01	-0.17	0.03
Surface moisture content, %	0.42	0.55[a]	-0.09	0.42	-0.31	-0.46	0.14	0.30	-0.32
Days since rain	0.85[a]	0.69[a]	0.68[a]	0.03	0.17	0.07	0.31	0.33	0.51[a]
Av. windspeed	0.46	0.52[a]	0.30	0.15	0.22	-0.10	0.48	0.60[a]	0.62[a]

[a] This correlation is significant at the 95 percent confidence level for the number of data pairs input (usually 17).

Many of the correlations with the selected meteorological variables were significant at the 95 percent level. This revealed that fugitive dust generation during these short-term sampling periods was more closely related to soil moisture and windspeed than it was to activity rates. The relatively high correlations with meteorological variables were unexpected, considering that changes in the source-to-sampler distances from test to test (as well as variable activity rates) probably caused some variance in concentrations. Concentrations downwind of paved roads had the lowest correlations, so presumably paved road emission rates were not as strongly influenced by meteorological conditions (it should be noted that high correlations do not indicate a cause-and-effect relationship). There is no need to adjust the concentration data for meteorological conditions before ranking the source impacts because the same met conditions prevailed at all three sampling locations due to simultaneous sampling.

The correlation analyses shown in Table 12 were also performed on two data subsets--the 10 tests with no watering and the 7 tests with watering--to determine whether the control-no control variable between tests was obscuring some relationships in the full data set. In general, correlations for the partial data sets were similar to those in Table 12, although the smaller sample sizes did result in a few apparent anomalies such as high negative correlations between activity rates and concentrations. A higher correlation is required for a value to be significant at the 95 percent level with fewer data pairs ($r>0.63$ for 10 pairs and $r>0.75$ for 7 pairs), so no additional significant relationships were identified in this exercise.

The activity and meteorological data used in the linear regression analysis are presented in Appendix Table A-1.

In addition to the evaluation of the effects of independent variables on measured concentrations, the data were reviewed for internal consistency. The two important characteristics of the data for quality control are a consistent reduction in concentrations with distance from the source (indicative of a Gaussian plume and no local interferences) and downwind concentrations all higher than corresponding upwind concentrations. The haul road samples had the best reductions with distance--12 sampling periods had the three concentrations in regular descending order and the other five sampling periods had one concentration out of order. The crusher/storage area, a more dispersed source with several possibilities for irregular plume formation or interferences, had 10 tests with concentrations in consistent descending order, six tests with one concentration out of order, and one test with no samples. The paved road samples produced the poorest quality data, with seven consistent sampling periods, six with one sample out of order, and five with inverted concentrations from the front to the back samplers. The lack of distinct reductions in

concentrations away from the paved road is not readily explainable. In some cases, all three concentrations were very low and only increased by a few μg/m³ with distance. However, the paved road data should be used with caution because of the large number of inconsistent readings.

The downwind concentrations were, with four exceptions out of 147 samples, always higher than upwind concentrations. Also, the arithmetic average upwind concentration for all 17 short-term tests was 68.9 μg/m³, only slightly higher than background and almost the same as that for the 24-h measurements. Both of these findings indicate that upwind samples were not affected by wind reversals or localized interferences during the sampling.

Comparison of average concentrations for the 7 controlled tests and 10 uncontrolled tests provided estimates of the effectiveness of watering in reducing dust emissions separate from those of the three months of 24-hour samples. These estimates are specific for haul road and crusher/storage area emissions rather than for the entire quarry. The results, summarized in Table 13, showed watering reduced concentrations downwind of haul roads by an average of 72.4 percent and reduced concentrations downwind of the crusher/storage area by 60.3 percent.

However, some of the independent variables that were found to have a significant effect on particulate concentrations had greatly different values in the two data subsets and therefore influenced the apparent differences in concentrations. Average values for the significant variables for the entire 17 tests and for the two subsets were as follows:

Variable	Av for all tests	Av for no-water tests	Av for water tests
Eqpt in crusher area	4.44	5.0	3.71
Surface moisture content, %	3.27	3.28	3.26
Days since rain	2.24	3.1	1.0
Average windspeed, mps	2.65	3.0	2.2

All three variables that had widely different values in the two subsets were higher during the period with no watering. In each case, this further increased concentrations for the uncontrolled tests and made the apparent effect of watering greater.

The equations for the lines of best fit from the linear regression analyses were used to adjust both the uncontrolled and controlled test data to the average values for significant variables shown in the second column above. The equations are as follows:

TABLE 13. EFFECT OF WATERING IN REDUCING PARTICULATE CONCENTRATIONS

Source/site	Av. conc for uncontrolled tests, μg/m³	Av. conc for controlled tests, μg/m³	Reduction due to control, %
Haul road			
First site	2471.2	546.6	77.9
Second site	953.9	226.7	76.2
Third site	505.8	186.8	63.1
All sites			72.4
Haul road (data adjusted for days since rain)			
First site	1722.3[a]	851.7	50.5
Second site	764.5	445.6	41.7
Third site	417.4	369.0	11.6
All sites			31.1
Crusher/storage area			
First site	2313.7	992.7	57.1
Second site	1327.8	665.7	50.6
Third site	1279.7	343.9	73.1
All sites			60.3
Crusher/storage area (data adjusted for windspeed and equipment in area)			
First site	1880.0	1199.7	36.2
Second site	1065.8	871.2	18.3
Third site	932.4	724.1	22.3
All sites			25.6

[a] For example, the line of best fit or regression equation at the first site for the 10 uncontrolled tests is:

$$TSP = 870.8\ DSR - 228.3$$

When the average DSR value of 2.24 (see P. 45) is substituted into this equation, an adjusted TSP value of 1722.3 results.

Haul road

First site, uncontrolled - TSP = 870.8 DSR - 228.3
First site, controlled - TSP = 246.0 DSR + 300.7
Second site, uncontrolled - TSP = 526.3 DSR - 414.4
Second site, controlled - TSP = 176.5 DSR + 50.2
Back site, uncontrolled - TSP = 335.4 DSR - 533.9
Back site, controlled - TSP = 129.5 DSR + 78.9

Crusher/storage area

First site, uncontrolled -

$$TSP = (358.6\ WS + 1162.3)\left(\frac{576.19\ EQ_{unc.} - 821.08}{TSP_{1st\ site,\ unc.,\ unadj.}}\right)$$

First site, controlled -

$$TSP = (-176.7\ WS + 1371.4)\left(\frac{576.19\ EQ_{cont.} - 821.08}{TSP_{1st\ site,\ cont.,\ unadj.}}\right)$$

Second site, uncontrolled -

$$TSP = (218.6\ WS + 626.0)\left(\frac{248.66\ EQ_{unc.} - 69.70}{TSP_{2nd\ site,\ unc.,\ unadj.}}\right)$$

Second site, controlled -

$$TSP = (46.3\ WS + 556.4)\left(\frac{248.66\ EQ_{cont.} - 69.70}{TSP_{2nd\ site,\ cont.,\ unadj.}}\right)$$

Back site, uncontrolled -

$$TSP = (240.9\ WS + 506.2)\left(\frac{306.82\ EQ_{unc.} - 491.27}{TSP_{3rd\ site,\ unc.,\ unadj.}}\right)$$

Back site, controlled -

$$TSP = (79.6\ WS + 173.3)\left(\frac{306.82\ EQ_{cont.} - 491.27}{TSP_{3rd\ site,\ cont.,\ unadj.}}\right)$$

where DSR = days since rain

WS = windspeed, m/s

EQ = average pieces of equipment operating

Concentrations from the paved highway sampling did not have a substantial difference between the first 10 tests and the last 7 tests (5.4 percent lower for the latter tests). No control

measures were applied to this source, so no difference was expected. The uneven effects of days since rain and windspeed on the two subsets were not obvious because neither of these variables had a significant effect on concentrations downwind of paved roads (see Table 12).

5.4 EMISSION ESTIMATES

Emission rates for each time period can be calculated using appropriate atmospheric dispersion equations and measured net concentrations, distances, activity rates, and meteorological parameters. The purpose of this effort is to obtain empirical values for comparison with the emission factors currently used by Illinois EPA to estimate quarry emissions. In effect, these dispersion calculations are the reverse of the modeling process used by Illinois EPA to predict the impact of a quarry on ambient concentrations. The line source and area source dispersion equations are as follows:

<u>Line Source Equation</u>

$$\chi = \frac{2q}{\sin \phi \sqrt{2\pi} \ \sigma_z \ u} \qquad \text{(Eq. 1)}$$

where χ = plume centerline concentration at a distance x downwind from the mining source, g/m^3

q = line source strength, g/s-m

ϕ = angle between wind direction and line source

σ_z = the vertical standard deviation of plume concentration distribution at the downwind distance x, for the prevailing atmospheric stability and including an initial σ_z, m

u = mean windspeed, m/s

The calculated values of q are converted to an emission rate per vehicle per mile by dividing by the number of vehicle passes and converting to appropriate units.

<u>Area Source Equation</u>

$$\chi = \frac{Q}{\pi \sigma_y \sigma_z u} \qquad \text{(Eq. 2)}$$

where Q = area source strength, g/s

σ_y = the horizontal standard deviation of plume concentration distribution at the downwind distance x, for the prevailing atmospheric stability and including an initial σ_y, m

χ, σ_z, u = same as Equation 1

The area source equation assumes that sampling is done along the plume centerline. If samplers are not continuously on the centerline because of varying wind directions or emission heights, the reduction(s) from centerline concentrations are calculated with the following equations:

$$\text{reduction factor}_y = \exp - \left[\frac{1}{2} \left(\frac{y}{\sigma_y}\right)^2\right] \qquad \text{(Eq. 3)}$$

$$\text{reduction factor}_z = \exp - \left[\frac{1}{2} \left(\frac{H}{\sigma_z}\right)^2\right] \qquad \text{(Eq. 4)}$$

where y = average horizontal distance from plume centerline to sampler, m

H = average vertical distance from plume centerline to sampler, m

With these equations, each downwind concentration produces a separate estimate of the source's emission rate--or three estimates per source per sampling period. The three estimates should not be the same if there is any deposition occurring because the depleted concentrations measured at successive distances would indicate progressively lower apparent emission rates. Theoretical particulate deposition equations predict reductions in apparent emission rates of 5 to 20 percent from those at the front sampler over the distances involved in the short-term sampling (assuming a windspeed of 3 to 5 mps and a mass median diameter of 15 to 20 μm).[4]

Emission rates calculated for each test are presented in Appendix B. These data are summarized by source in Table 14.

The haul road was the only source that exhibited deposition. Its data showed relatively high rates of deposition (averages of 23 to 53 percent), as previously noted in the discussion of downwind concentrations. The most likely explanation for the high deposition rates, considering the variables in the theoretical deposition equations and the lack of deposition for the other two sources sampled simultaneously, is that haul roads emit larger particles than the other sources. Published research work done by Midwest Research Institute supports this hypothesis.[5,6]

TABLE 14. AVERAGE EMISSION RATES FROM DISPERSION CALCULATIONS

Source	Watering for dust control	Av. emission rate, lb/veh-mi[a]			Relative standard deviation of data ($s/\bar{x}$)		
		First samplers[b]	Middle samplers	Back samplers	First samplers	Middle samplers	Back samplers
Haul road	No	33.5	20.1	15.9	0.60	0.98	1.04
	Yes	8.3	6.4	6.1	1.65	1.71	1.90
Paved road		0.34	0.41	0.38	1.35	0.94	1.13
Crusher/ storage area	No	15.5	18.0	25.8	0.63	0.50	0.48
	Yes	3.8	6.1	5.7	0.43	0.69	0.60

a Units of lb/hour for the crusher/storage area.
b Best estimate for emission factor because very little deposition has occurred at this distance.

Calculated paved road emission rates were fairly constant with distance from the road. The lowest apparent emission rates were from the sites nearest the road, but these samples also displayed the greatest variability (relative standard deviation). A possible reason for the greater variability and slightly lower apparent emission rate is that the plumes may still be in turbulent mixing at this downwind distance (55 to 90 ft) as a result of vortices from high speed traffic on this state highway.

The consistent increases in apparent emission rates with distance from the crusher is attributed to lack of well-defined source boundaries (and therefore imprecise source-receptor distances) and localized entrainment from the dusty surface on which the samplers were located in the storage area. The deposition that was occurring was being masked by additional particulate matter being picked up as the plume moved toward the samplers. If this explanation is correct, the emission estimates from the first row of samplers are probably the most accurate.

The high test-to-test variability indicated by the relative standard deviations and sampling problems noted above such as turbulence in the plume and poorly defined source boundaries could be interpreted as producing unreliable results. However, the test-to-test variations and problems with these short-term sampling periods were no greater than those experienced with other fugitive dust testing efforts; results should be considered state-of-the-art.

The effectiveness of watering in reducing dust is about the same when calculated from emission rates as when calculated from ambient concentrations. No effort was made to adjust emission rates to average conditions of soil moisture, windspeed, etc.

A comparison of the calculated emission rates from the short-term sampling with those currently used by Illinois EPA is presented in Section 6.

SECTION 6

COMPARISON OF RESULTS WITH PREVIOUSLY AVAILABLE DATA

The results of this study can be compared on three different bases with data currently being used for air quality assessments of quarries--emission factors, predicted ambient impact, and control efficiency attributed to watering. Each of these comparisons is covered in a subsection below.

6.1 EMISSION FACTORS

Average emission rates were determined for three different sources at the quarry: the main haul road, the paved highway that provides access to the quarry, and the crusher/storage area. They were previously presented in Table 14.

The emission factor equations that Illinois EPA uses to calculate quarry emissions are summarized in Table 15. Three emission factors are from a recent publication entitled <u>Fugitive Emissions from Integrated Iron and Steel Plants</u>.[5] PEDCo has also sampled the three types of sources at other facilities and developed emission factors using the same upwind-downwind sampling configuration and dispersion equations as in the present study. Emission rates from the present study, Illinois EPA's current emission factors, and previous PEDCo emission data are compared in Table 16.

Available emission factors for all three sources are lower than measured emission rates. The Illinois EPA factors provide a better estimate than the previous PEDCo average emission rates in all three cases, indicating that equations with several correction parameters may have greater predictive capabilities than single-value emission factors. Considering the assumptions that must be made in order to quantify the correction parameters, agreement between measured and predicted emission rates is acceptable. The emission factors used by Illinois EPA in quarry air quality impact analyses appear to be adequate for that purpose.

TABLE 15. FUGITIVE DUST EMISSION FACTORS CURRENTLY USED BY ILLINOIS EPA TO ESTIMATE QUARRY EMISSIONS

Source category	Measure of extent	Emission factor[a] (lb/unit of source extent)	Correction parameters
1. Unpaved roads	Vehicle - miles traveled	$5.9\left(\frac{s}{12}\right)\left(\frac{S}{30}\right)\left(\frac{W}{3}\right)^{0.7}\left(\frac{d}{365}\right)\left(\frac{w}{4}\right)^{0.5}$	s = Material silt content (%) S = Average vehicle speed (mph)
2. Paved roads	Vehicle - miles traveled	$0.09\left(\frac{s}{10}\right)\left(\frac{L}{1,000}\right)\left(\frac{W}{3}\right)^{0.7}\left(\frac{4}{n}\right)$	W = Vehicle weight (tons) L = Surface dust loading on traveled portion of road (lb/mile)
3. Batch load-in (e.g., front-end loader, railcar dump)	Tons of material loaded in	$0.0018\,\frac{\left(\frac{s}{5}\right)\left(\frac{U}{5}\right)}{\left(\frac{M}{2}\right)^{2}\left(\frac{Y}{6}\right)}$	U = Mean wind speed (mph) M = Material surface moisture content (%)
4. Continuous load-in (e.g., stacker, transfer station)	Tons of material loaded in	$0.0018\,\frac{\left(\frac{s}{5}\right)\left(\frac{U}{5}\right)}{\left(\frac{M}{2}\right)^{2}}$	Y = Dumping device capacity (yd^3) K = Activity correction
5. Storage pile maintenance and traffic	Tons of material stored	$0.10\ K\left(\frac{s}{1.5}\right)\left(\frac{d}{235}\right)$	d = Number of dry days per year f = Percentage of time wind speed exceeds 12 mph
6. Storage pile wind erosion	Tons of material stored	$0.05\left(\frac{s}{1.5}\right)\left(\frac{d}{235}\right)\left(\frac{f}{15}\right)\left(\frac{D}{90}\right)$	D = Duration of material storage (days) e = Surface erodibility (tons/acre/year)
7. Batch load-out	Tons of material loaded out	$0.0018\,\frac{\left(\frac{s}{5}\right)\left(\frac{U}{5}\right)}{\left(\frac{M}{2}\right)^{2}\left(\frac{Y}{6}\right)}$	P - E = Thornthwaites precipitation-evaporation index n = No. of lanes
8. Wind erosion of exposed areas	Acre-years of exposed land	$3,400\,\frac{\left(\frac{e}{50}\right)\left(\frac{s}{15}\right)\left(\frac{f}{25}\right)}{\left(\frac{P-E}{50}\right)^{2}}$	w = No. of wheels

[a] Annual average emissions of dust particles smaller than 30 μm in diameter based on particle density of 2.5 g/cm^3.

Source: Reference 5.

TABLE 16. COMPARISON OF EMISSION FACTORS WITH MEASURED EMISSION RATES

Source	Average uncontrolled emission rate, lb/veh-mi[a]		
	Present study[b]	Illinois EPA emission factor[c]	Previous PEDCo data
Haul road	33.5	18	14
Paved road (dirty)	0.34	0.055	0.04
Crusher/ storage area	15.5	15	13

[a] Units of lb/hour for the crusher/storage area.

[b] Average of emission rates at the first downwind distance, where deposition losses are minimal.

[c] Calculated from equations in Table 6-1 with the following inputs:

Haul road (Eq. 1)

s = 13.4% silt
S = 20 mph
W = 40 tons gross wt
d = 241 days (from IEPA)
w = 10

Paved road (Eq. 2)

s = 6.1% silt
L = 1000 lb/mi
W = 3 tons
n = 4 lanes

Crusher/conveyor/ storage piles (Eq. 3, 5, 6, and 7)

s = 3.0% silt
U = 10.2 mph (from IEPA)
M = 3.5% moisture
Y = 6 cu yd

d = 241 days (from IEPA)
f = 31% (from IEPA)
D = 120 days
k = 1 (from IEPA)

6.2 AMBIENT IMPACT OF QUARRIES

Illinois EPA could not produce modeling results specific for the quarry that was sampled in time for inclusion in this report. However, several large quarries (>500,000 ton/yr) in the state have been modeled, with predicted annual arithmetic mean contributions as high as 65 $\mu g/m^3$ at distances of 0.5 km from the quarries.[7] Average model-predicted impacts at distances of 0.5 to 0.7 km were 30 to 50 $\mu g/m^3$.

During the 3-month sampling study, the impact of the quarry averaged 16 to 29 $\mu g/m^3$ (at 0.7 and 0.5 km, respectively) on days with quarrying operations. These averages included days with rain and limited operations. On weekends and holidays, the impact of the quarry was 11 to 15 $\mu g/m^3$.

If it is assumed that the quarry has 200 days per year with operation and 165 days with no operation or with snow cover, the annual average impact from the quarry (based on sampling data) would be 14 to 23 $\mu g/m^3$, slightly less than half the model's predictions for a large quarry. Part of the apparent overprediction by dispersion models may be because the sampled quarry has a production of 400,000 ton/yr, less than the previously modeled quarries. Another potential reason for overprediction is failure to consider particle deposition in the modeling. The high average ratio of IP to TSP concentrations observed at the quarry would indicate that substantial deposition had already occurred at 0.5 km from the center of the quarry and that little additional deposition would be expected beyond that distance.

Illinois EPA plans to review its modeling data along with this report and draw additional conclusions on the accuracy of their current modeling procedures.

6.3 CONTROL EFFICIENCY OF WATERING

Four primary references were found that contained data evaluating watering as a dust control measure for operations similar to those at the quarry. All four estimated the control efficiency of a regular watering schedule at 50 percent, and all were based on emission reductions from specific sources (such as a single section of haul road) rather than the overall ambient impact of a watering program. Information from the references is summarized in Table 17.

Despite the consensus in the literature, watering gave only a 31 percent reduction in particulate concentrations downwind of haul roads and a 26 percent reduction downwind of the crusher/ storage area, after adjustment of data for the effect of three

TABLE 17. PREVIOUS EVALUATIONS OF WATERING FOR DUST CONTROL

Quarry source controlled	Reference	Page No.	Estimated control, %
Haul roads and storage areas	Jutze, G. and K. Axetell. Investigation of Fugitive Dust, Volume I--Sources, Emissions, and Control. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. EPA-450/3-74-036a. June 1974.	4-21	50
Storage pile area	PEDCo Environmental, Inc. Technical Guidance for Control of Industrial Process Fugitive Particulate Emissions. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. EPA-450/3-77-010. March 1977.	2-38	50
Haul roads	Survey of Fugitive Dust from Coal Mines. U.S. Environmental Protection Agency, Denver, Colorado. EPA-908/1-78-003. February 1978.	70	20-50
Haul roads	Bohn, R., T. Cuscino, and C. Cowherd Fugitive Emissions from Integrated Iron and Steel Plants. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. EPA-600/2-78-050. March 1978.	6-15	50

independent variables. Prior to adjustment, the apparent reductions were 72 and 60 percent, respectively, but it was obvious that differences in the weather and operations between the two time periods were responsible for part of the measured reductions.

A possible reason for the less than 50 percent efficiency was that watering at the quarry was accomplished by tipping a front-end loader bucket full of water rather than by spraying with a water truck. The resulting surface wetting was not as even, nor did it cover as large an area.

No impact was found on ambient concentrations downwind of the quarry as a result of watering. An impact less than that observed with the short-term individual-source sampling was expected because all areas of the quarry were not watered. However, no explanation can be provided for the complete lack of effect from watering.

SECTION 7

SUMMARY AND CONCLUSIONS

Impact of Quarry on Ambient Particulate Concentrations

Sampling sites with 24-hour hi-vols were located at distances of 0.5 and 0.7 km from the suspected area of highest emissions on both the north and south sides of the quarry. Therefore, one set of samplers was in the prevailing upwind direction each day and the other set was downwind; valid upwind-downwind samples could be obtained on most days with this configuration. Directional hi-vol samplers, all set to the same quadrant, were collocated with the 24-hour hi-vols at each of the four sites so that part day upwind-downwind data were also generated on days with highly variable winds. The distances of 0.5 and 0.7 km could be considered closest ambient locations, or fenceline, for a typical quarry in Illinois.

The measured particulate concentrations consistently showed an increase downwind of the quarry compared to the upwind concentration. The impact averaged 30 $\mu g/m^3$ at 0.5 km and 15 $\mu g/m^3$ at 0.7 km on days with quarry operations. On days with no activity, the quarry still had an impact of 15 $\mu g/m^3$ at 0.5 km and 11 $\mu g/m^3$ at 0.7 km. Clearly, the quarry's impact decreased rapidly with distance.

The measured net concentrations were a little less than half of Illinois EPA's model-predicted annual average concentrations (30 to 50 $\mu g/m^3$) at the two sampling distances. However, the modeling results were for several other quarries in the state, most with greater production than the 400,000 ton/yr produced at the quarry being studied.

Major Emission Sources at Quarry

The crusher/storage area appeared to have a greater effect on air quality than pit operations such as the haul roads. In 17 short-term sampling periods of one to three hours each, samplers downwind of the crusher/storage area had the highest concentrations for 11 of the periods. Also, amount of rock loaded in the crusher/storage area was the variable with the highest correlation with particulate concentrations in the multiple linear regression analysis (out of 10 variables).

The short-term sampling to compare the relative impacts of three major sources produced two other important findings. Concentrations downwind of the main haul road decreased much more rapidly than those from the crusher/storage area or paved highway, leading to the conclusion that emissions from this source had a larger average particle size. Secondly, the paved highway created higher net concentrations at the farthest downwind samplers (60 to 80 m) than the unpaved haul road. The relatively high emission rates from the highway were attributed to trackout from the quarry entrance, high average speeds along that section, and unpaved shoulders. Because of the localized trackout, the impact is probably not representative of emissions from the road at distances more than about 0.1 mi from the entrance.

Calculations were performed with dispersion equations to convert the short-term net concentrations into corresponding emission rates. The average emission rates for the three sources were 3 to 518 percent greater than the emission factors currently being used by Illinois EPA to estimate emissions from quarries.

Effect of Watering

The quarry operator participated in the study by watering as he normally would during alternating 2-week periods and not watering during the intervening periods. Watering was done primarily by hauling water in the buckets of front-end loaders and dumping it along the traveled roads in the pit, throughout the production area, and around storage piles. A water spray was added on the conveyor from the crusher. The differences in average concentrations for the watering and no watering periods were not significant (at the 0.10 level) at the 0.5 km or 0.7 km samplers; in fact, slight increases in average 24-hour concentrations were observed with watering. However, the short-term sampling was also divided equally into watering/no watering tests, and the watering reduced net concentrations downwind of the haul roads and crusher/storage area by 31 and 26 percent, respectively, after adjustment for the effect of other significant independent variables. The control efficiency for frequent watering most commonly reported in the literature is 50 percent.

Size Distribution of Ambient Particulate near Quarry

The concentration of particles less than 15 μm in diameter was determined by taking 24-hour samples each day with size-selective hi-vols at the two 0.5 km sites. The ratio of IP to TSP concentrations averaged 0.71 at the south site and 0.85 at the north site. These were higher than the average of 0.65 reported by EPA for several urban sites, indicating that particles remaining suspended at a distance of 0.5 km from the quarry were mostly in the inhalable size range and not the large, settleable particles normally attributed to quarries.

Upwind Concentrations

The geometric mean of upwind concentrations for the 74 sampling days was 64.5 $\mu g/m^3$. This was about equal to rural background for an agricultural area in Illinois, but may have reflected some residual impact from the quarry on days with variable winds. However, it was low enough to indicate that there were no other major particulate sources in the immediate vicinity of the quarry.

Effects of Other Independent Variables

The effects of both source-related and meteorological variables on particulate concentrations were assessed by a multiple linear regression analysis. None of the meteorological variables (such as surface moisture content or average wind speed) produced high correlations with the 24-hour data, although days since rain and wind speed were both found to be significant variables with simple linear regression of the short-term data. The only variable that was consistently significant at the 0.05 level was the amount of crushed rock shipped per day (related to activity in the crusher/storage area).

The multiple linear regression analysis provided some indications that the public unpaved road along the south boundary of the quarry was contributing to the southern samplers on days with wind from the north, and thereby increasing the apparent impact from the quarry. This indication was a marginally significant positive correlation in two of the nine MLR runs (see Tables 5 and 6). The sampling sites were at distances of approximately 50 m and 250 m from the unpaved road, which had a traffic volume of about 90 vehicles/day.

To confirm this potential interference, average net concentrations with winds from each of the two directions were compared. Net concentrations were on average of 3.2 $\mu g/m^3$ higher at southern hi-vol samplers than at the northern ones, but the IP concentrations were an average of 9.5 $\mu g/m^3$ higher at the northern sampler (see Table 8). Therefore, no significant impact could be proven. It was also noted that only 30 percent of the sampling days had predominantly northern winds, so even if there were a small interference from the unpaved road on these days it would not distort the overall results.

Another potential interfering source, the asphalt batch plant across the highway from the quarry, was included in the data analysis. The plant had wide variations in operation over the period of the study, but these variations did not correlate with any of the measured particulate concentrations around the quarry.

REFERENCES

1. Technical Manual for Measurement of Fugitive Emissions: Upwind/Downwind Sampling Method for Industrial Pollutants. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. Publication Number EPA-600/2-76-0892. April 1976.

2. Survey of Fugitive Dust from Coal Mines. U.S. Environmental Protection Agency, Denver, Colorado. EPA-908/1-78-003. February 1978.

3. Communication with Thompson Pace, Monitoring and Data Analysis Division, Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency. May 19, 1980.

4. Meteorology and Atomic Energy. U.S. Atomic Energy Commission, Oak Ridge, Tennessee. Publication Number TID-24190. July 1968. p. 202-208.

5. Bohn, R., T. Cuscino, and C. Cowherd. Fugitive Emissions from Integrated Iron and Steel Plants. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. EPA-600/2-78-050. March 1978.

6. Quantification of Dust Entrainment from Paved Roadways. Midwest Research Institute, Kansas City, Missouri. Prepared under EPA Contract No. 68-02-1403. March 1977.

7. Communication with John Schrock, Illinois Environmental Protection Agency, Springfield, Illinois. September 1980.

APPENDIX A

RAW DATA FROM FIELD TESTS

TABLE A-1. SOURCE ACTIVITY AND METEOROLOGICAL DATA FOR SHORT-TERM TESTS

	Source activity data							Meteorological data		
Test	No. of haul trucks	No. of other veh	No. of veh on paved rd	Trucks on paved road	Trains	Eqpt in crusher area	Trucks loaded that day	Surface moisture, %	Days since rain	Wind speed, mps
1	29	10	340	35	?	6	90	2.93	2	2.2
2	8	0	728	52	3	no samples		2.93	2	1.1
3	40	6	626	112	4	6	112	3.98	3	4.7
4	73	9	946	44	4	6	112	3.98	3	5.1
5	50	8	1015	?	2	4	80	5.29	4	3.8
6	37	0	855	45	3	4	80	5.29	4	4.2
7	57	15	780	105	?	3	50	3.69	6	4.7
8	9	0	918	85	?	6	114	1.65	2	1.8
9	14	0	420	30	3	6	114	1.65	2	1.1
10	59	16	627	76	4	4	113	1.40	3	1.3
11	61	17	779	171	3	3	65	3.34	0	2.5
12	54	6	918	36	5	3	65	3.34	0	2.2
13	36	4	735	135	4	4	94	3.38	1	1.0
14	46	5	588	56	2	4	94	3.38	1	1.0
15	41	12	876	36	3	4	94	3.38	1	1.8
16	20	3	615	30	3	4	166	2.99	2	3.4
17	6	3	594	44	3	4	166	2.99	2	3.1

TABLE A-2. SOIL SIZE DISTRIBUTION ANALYSES

Sieve size, mm	Percent retained on sieve			
	Haul road, 6/7/80	Haul road, 7/30/80	Hwy track-out, 6/7/80	Hwy track-out, 7/30/80
19.05	1.1	0	0	0
12.70	0	9.3	3.6	8.2
9.52	2.0	7.2	10.8	5.4
4.76	7.4	13.8	27.2	23.9
2.38	18.3	14.8	16.8	17.8
1.19	23.4	18.3	12.7	16.2
0.50	13.9	10.3	8.9	11.2
0.42	5.6	3.8	3.4	3.9
0.298	3.6	2.7	2.5	2.7
0.149	5.9	4.4	3.8	3.8
0.074	4.0	3.5	2.8	2.2
Pan (<0.074)	14.8	11.9	7.5	4.7

TABLE A-3. HI-VOL MEASUREMENTS FROM FIXED SAMPLING NETWORK

Date	Direction det'd to be upwind	TSP concentrations at south samplers, μg/m³				TSP concentrations at north samplers, μg/m³			
		0.5 km dir	0.7 km dir	0.5 km 24-h	0.7 km 24-h	0.5 km dir	0.7 km dir	0.5 km 24-h	0.7 km 24-h
5-07	S	145	85	167	98	158	286	79	96
5-08	S	144	67	154	83	228	202	62	5
5-09	S	44	72	109	78	95	89	81	92
5-10	S	118	97	106	n.d.	134	117	117	139
5-12	S	254	215	71	29	277	263	65	54
5-14	S	n.d.	n.d.	n.d.	n.d.	72	10	44	42
5-15	S	147	91	52	76	77	77	73	80
5-16/17/18	S	185	136	61	60	108	112	58	35
5-19	S	61	n.d.	63	58	55	54	61	69
5-20	N	n.d.	n.d.	86	87	n.d.	n.d.	38	92
5-21	S	2401	1624	120	89	n.d.	n.d.	102	113
5-22	S	390	191	95	90	128	43	84	91
5-23/24/25	S	189	129	85	78	93	99	88	93
5-26	N	99	105	72	76	101	39	81	83
5-27	N	129	126	77	74	127	126	110	87
5-28	S	182	182	160	63	124	127	73	49
5-29	S	107	107	109	103	123	96	118	123
5-30	S	260	208	250	191	294	223	270	266
5-31	S	156	167	101	86	149	146	77	54
6-01	S	57	47	83	53	209	216	67	75
6-02	S	39	40	30	25	29	29	31	29
6-03	S	68	68	62	56	69	63	51	56
6-04	N	49	59	43	37	615	877	35	39
6-05	S	122	644	79	102	122	124	105	110
6-06	S	88	77	93	82	n.d.	93	n.d.	86
6-07	N	n.d.	n.d.	55	44	n.d.	n.d.	61	34

(continued)

TABLE A-3 (continued)

Date	Direction det'd to be upwind	TSP concentrations at south samplers, μg/m^3				TSP concentrations at north samplers, μg/m^3			
		0.5 km dir	0.7 km dir	0.5 km 24-h	0.7 km 24-h	0.5 km dir	0.7 km dir	0.5 km 24-h	0.7 km 24-h
6-08	N	57	34	57	33	26	34	29	33
6-09	N	n.d.	n.d.	100	96	n.d.	n.d.	97	103
6-10	N	130	80	86	74	66	81	65	65
6-11	S	90	99	38	54	80	90	66	84
6-12	S	n.d.	65	74	72	66	77	76	71
6-13	S	89	88	84	86	140	125	122	115
6-14	S	102	99	96	98	104	60	98	93
6-15	N	45	42	47	48	50	48	46	44
6-16	N	38	33	40	38	34	34	34	32
6-17	S	60	56	48	48	117	92	77	55
6-18	S	65	64	61	n.d.	92	81	79	69
6-19	N	210	119	134	99	87	86	80	89
6-20	N	59	52	49	37	51	53	n.d.	32
6-21	S	67	n.d.	58	n.d.	89	82	72	69
6-22	S	74	69	86	69	17	0	87	22
6-23	S	195	261	93	119	102	89	61	63
6-24	S	n.d.	n.d.	58	0	10	0	4	61
6-25	S	n.d.	n.d.	n.d.	60	n.d.	83	63	4
6-26	S	103	n.d.	87	91	104	107	91	88
6-27	N	248	n.d.	132	n.d.	167	195	123	124
6-28	S	n.d.	89	84	n.d.	156	248	112	99
6-29	N	n.d.	n.d.	71	58	n.d.	n.d.	50	n.d.
6-30	N	n.d.	n.d.	120	56	n.d.	n.d.	41	104
7-01	S	141	106	88	81	62	204	2	62
7-03	N	264	155	245	113	102	103	77	78
7-07	S	98	91	205	93	121	10	114	116

(continued)

TABLE A-3 (continued)

Date	Direction det'd to be upwind	TSP concentrations at south samplers, μg/m³ 0.5 km dir	0.7 km dir	0.5 km 24-h	0.7 km 24-h	TSP concentrations at north samplers, μg/m³ 0.5 km dir	0.7 km dir	0.5 km 24-h	0.7 km 24-h
7-08	S	78	<u>79</u>	99	91	87	98	85	86
7-09	N	99	90	46	44	190	134	70	<u>76</u>
7-11	N	158	159	73	57	n.d.	n.d.	85	<u>67</u>
7-12	S	84	74	80	<u>76</u>	n.d.	n.d.	79	70
7-13	N	76	52	n.d.	34	52	55	39	<u>38</u>
7-14	S	106	<u>99</u>	86	<u>99</u>	146	130	140	109
7-15	S	n.d.	n.d.	131	<u>90</u>	n.d.	n.d.	280	180
7-16	S	232	182	131	<u>85</u>	255	223	120	105
7-17	N	n.d.	n.d.	169	42	n.d.	n.d.	81	<u>50</u>
7-18	S	40	<u>47</u>	83	56	110	31	84	71
7-19	N	n.d.	n.d.	90	78	236	246	81	<u>81</u>
7-20	N	n.d.	n.d.	105	92	n.d.	n.d.	<u>73</u>	97
7-21	S	n.d.	n.d.	59	<u>37</u>	n.d.	n.d.	82	63
7-22	N	187	134	171	125	101	112	77	<u>79</u>
7-23	N	73	60	56	60	76	80	60	<u>61</u>
7-24	N	71	58	59	44	84	64	62	<u>57</u>
7-25	S	49	86	52	<u>46</u>	82	83	62	55
7-26	N	139	138	86	80	162	n.d.	80	<u>45</u>
7-28	N	215	205	243	118	n.d.	356	122	<u>57</u>
7-29	S	343	216	201	<u>73</u>	210	225	110	87
7-30	S	127	<u>55</u>	65	62	117	90	44	62
7-31	S	102	94	94	<u>84</u>	158	139	145	102

Note: The underlined concentration on each line was selected as representative upwind concentration for that day. The selection procedure is described on Pages 24 and 25.

TABLE A-4. MULTIPLE LINEAR REGRESSION INPUT DATA

DATE	NET TSP CONC, ug/m³ 5DIR	7DIR	.5	.7	IP	PRODUCTION	SALES	TRAF. VOL	CONST TRK	% MOIST	DSR	WIND SPD	WIND DIR
507	73	201	6	11		675	2000	90	0	2.2	4	8.2	0
508	161	135	5	62		2021	2161	90	0	1.0	5	5.8	0
509	23	17	0	20		2400	2400	90	0	5.8	0	1.9	0
510	37	20	20	42		0	0	90	0	6.0	0	10.1	0
512	240	234	36	25		2475	1617	90	0	7.0	0	6.8	0
514	62	0	34	32		2500	1434	90	0	7.0	0	5.7	0
515	1	1	0	4		1800	1450	90	0	4.8	1	10.6	0
517	40	52	0	0		0	0	90	0	6.0	0	5.0	0
519	0	0	3	11		2400	2859	90	0	6.0	0	6.3	0
520			48	49		2100	1852	90	0	4.5	1	3.8	0
521	·		13	24		115	1647	90	0	3.5	2	5.4	0
522	38	0	0	1		2550	1514	90	0	2.5	3	6.7	0
524	10	21	10	15		0	0	90	0	5.8	0	6.4	0
526	60	66	33	37		0	0	90	0	3.3	2	8.4	1
527	42	39	0	0		0	1430	90	1	2.1	3	4.0	1
528	61	64	10	0		425	1698	90	1	2.1	4	7.1	0
529	20	0	15	20		25	1511	93	1	6.2	0	7.3	0
530	103	120	79	75		0	1262	87	1	3.5	0	13.4	0
531	63	60	0	0		0	0	71	1	3.0	1	8.2	0
601	156	163	14	22		0	0	67	1	7.9	0	10.0	0
602	4	4	6	4		52	553	65	1	6.5	0	7.9	0
603	13	7	0	0		1750	1659	81	1	5.4	1	7.7	0
604	20	10	4	0		2300	1443	94	1	4.8	2	3.2	1
605	20	22	3	8		1200	1610	83	1	4.1	3	11.0	0
606	20	16	12	9		1775	1213	112	1	5.2	0	7.1	0
607	[illegible]		21	10		0	1088	84	1	6.5	0	9.4	1
608	24	1	24	0		0	0	77	1	4.9	1	11.2	1
609			3	0		0	1013	93	0	2.7	2	6.4	1
610	56	6	12	1		1925	2276	82	0	4.4	3	5.5	1
611	26	36	12	30		500	1236	133	0	2.9	4	2.7	0
612	1	12	11	6		975	1564	125	0	4.0	5	6.7	0
613	52	37	34	27	47	1850	927	91	0	5.3	6	8.1	0
614	5	0	0	0	0	0	278	106	0	4.6	7	4.6	0
615	1	2	3	0	0	0	0	100	0	3.3	8	10.1	1
616	4	1	6	0	1	2450	610	85	0	3.7	1	7.2	1
617	69	44	29	7	13	1600	1356	78	0	1.6	2	2.6	0
618	28	17	15	5		1425	1457	97	0	1.4	3	2.8	0
619	121	30	45	10	0	1650	1153	74	0	3.6	4	11.4	1
620	27	20	17	0	0	1300	804	81	0	3.0	5	4.1	1
621	22	15	5	2	14	0	373	96	0	3.3	6	3.1	0
622	0	0	0	0	12	0	0	73	0	4.0	7	5.5	0
623	0	0	0	0	2	1625	1446	72	1	3.7	8	4.2	0
624	10	0	4	61	0	1700	727	67	1	3.3	0	3.6	0
625	0	23	3	0	0	1525	1029	73	1	3.4	1	2.4	0
626	13	16	0	0	9	850	2079	123	1	3.0	2	4.8	0
627	124	0	0	0	117	0	2476	104	1	3.4	3	7.2	1
628	67	159	23	10	21	0	905	70	1	3.5	0	6.1	0
629			21	8	30	0	0	156	1	3.7	1	8.2	1
630			0	48	12	0	2777	88	1	3.0	2	3.6	0 0
701	0	123	0	0	62	0	2001	87	1	2.5	3	6.0	0 0
703	186	77	167	35	55	0	1453	89	1	3.0	1	3.5	0 1
707	30	0	23	25	16	0	1315	93	1	2.2	3	7.1	2 0
708	8	19	6	7	0	0	921	83	1	2.0	4	5.7	2 0
709	14	23	0	0	4	2425	1236	72	0	4.5	0	4.0	2 1
711	91	92	6	0	69	2075	2037	101	0	2.6	2	2.1	2 1
712	7	0	3	0	4	0	428	83	0	2.5	3	6.7	0 1
713	38	14	0	0	7	0	0	91	0	2.0	4	3.3	0 1
714	47	31	41	10	35	2250	2291	106	0	2.0	5	9.2	2 0
715			190	90	82	2425	3226	98	0	1.8	6	8.5	2 1
716	127	77	26	0	22	1175	2512	85	0	1.7	7	10.0	2 1
717			119	0	33	1750	3169	78	0	1.3	8	7.3	2 1
718	63	0	37	24	13	725	1992	97	0	1.7	0	7.3	2 0
719			9	0	4	0	708	79	0	1.4	1	5.3	0 1
720			32	19	0	0	0	81	0	1.5	2	12.7	0 1
721			0	0	23	1250	1243	96	1	2.3	3	4.0	3 1
722	100	55	92	46	30	1250	1727	73	1	1.6	4	6.3	3 1
723	12	0	0	0	0	1975	1139	72	1	1.0	5	4.5	3 1
724	14	1	2	0	0	1450	1464	77	1	.9	6	2.2	3 1
725	36	9	16	37	18	0	1120	73	1	1.0	7	4.2	3 0
726	94	93	41	35	5	0	255	72	1	1.5	8	2.1	0 1
728	158	148	186	61	63	1500	2209	80	1	1.3	1	4.0	3 1
729	256	129	114	0	61	2350	1520	157	1	.4	2	4.4	3 1
730	62	35	0	7	7	2200	1249	88	1	1.1	3	6.6	1 0
731	74	55	61	18	24	2400	564	84	1	1.2	4	8.6	1 0

APPENDIX B

DATA TO CALCULATE ESTIMATED EMISSION RATES

TABLE B-1. EMISSION ESTIMATES FROM DISPERSION MODELING--HAUL ROAD

Test	Wind speed mps	Stab class	Plume/ source angle,°	Sample time, min	Activity rate	Estimated emission rate, lb/VMT		
						First samplers	Middle samplers	Back samplers
1	2.2	A	60	127.0	39	5.63	0.42	2.29
2	1.1	A	80	114.8	8	35.97	0	21.68
3	4.2	B	90	143.0	46	52.86	49.43	13.47
4	5.1	C	90	183.9	84	12.73	8.39	5.62
5	3.8	B	90	166.6	58	62.90	56.26	9.59
6	4.2	B	90	138.9	37	47.03	31.47	0
7	4.7	B	90	152.2	73	53.39	20.18	55.30
8	1.8	A	90	121.1	9	28.98	10.39	13.95
9	1.1	A	80	122.5	14	23.34	17.91	29.77
10	1.3	A	90	190.7	75	11.91	6.61	7.10
11	2.5	B	80	170.1	78	2.67	1.80	1.96
12	2.2	B	75	180.6	60	1.40	0	1.32
13	1.0	A	70	131.6	40	0.39	0.31	0.34
14	1.0	A	70	89.7	51	0.78	0.60	1.42
15	1.8	A	70	116.0	53	1.77	1.48	1.85
16	3.4	B	90	132.4	23	13.62	10.90	0
17	3.1	B	90	99.0	9	37.73	29.89	29.83

TABLE B-2. EMISSION ESTIMATES FROM DISPERSION MODELING--PAVED ROADS

Test	Wind speed mps	Stab class	Plume/ source angle,°	Sample time, min	Activity rate	Estimated emission rate, gm/VMT		
						First samplers	Middle samplers	Back samplers
1	2.2	A	60	116.4	390	21.30	52.83	57.16
2	1.1	A	80	119.6	728	4.66	15.70	23.63
3	4.7	B	70	119.4	686	167.19	304.15	0
4	5.1	C	75	119.4	946	176.38	295.07	393.47
5	3.8	B	90	171.1	1015	0	221.07	330.72
6	4.2	B	90	141.3	855	31.65	55.56	0
7	4.7	B	90	142.6	780	495.29	549.31	549.16
8	1.8	A	90	156.9	918	186.55	211.73	508.40
9	1.1	A	80	93.8	420	136.27	226.42	448.97
10	1.3	A	90	146.8	627	15.96	32.99	26.59
11	2.5	B	80	173.8	779	13.49	92.18	149.41
12	2.2	B	75	166.6	918	126.80	125.00	136.53
13	1.0	A	70	138.9	735	38.76	39.82	37.63
14	1.0	A	70	131.7	588	45.93	40.34	33.89
15	1.8	A	70	112.9	876	31.95	23.87	21.66
16	3.4	B	90	139.6	615	765.22	552.01	0
17	3.1	B	90	104.9	594	343.22	302.35	243.89

TABLE B-3. EMISSION ESTIMATES FROM DISPERSION MODELING--CRUSHER/STORAGE AREA

Test	Wind speed mps	Stab class	Sample time, min	Activity rate	Estimated emission rate, lb/hour		
					First samplers	Middle samplers	Back samplers
1	2.2	A	139.1	1	7.87	25.66	9.88
2	-	-	-	-	-	-	-
3	4.7	B	109.2	1	24.19	31.20	35.98
4	5.1	C	138.2	1	31.65	26.77	44.59
5	3.8	B	146.3	1	11.02	18.68	30.57
6	4.2	B	123.0	1	26.28	13.32	36.29
7	4.7	B	150.7	1	11.41	21.64	27.92
8	1.8	A	139.6	1	16.59	11.80	21.17
9	1.1	A	113.8	1	5.47	7.78	13.37
10	1.3	A	205.0	1	4.58	5.05	12.04
11	2.5	B	187.3	1	3.28	6.06	4.17
12	2.2	B	185.8	1	6.52	14.29	10.88
13	1.0	A	143.2	1	2.92	3.08	2.20
14	1.0	A	139.5	1	1.75	2.22	2.94
15	1.8	A	126.2	1	2.96	3.29	3.41
16	3.4	B	148.6	1	5.66	8.71	9.36
17	3.1	B	109.0	1	3.80	5.23	6.93

Critique of Report

"Impact of Stone Quarry Operations on Particulate Levels"

by

Dames and Moore, Inc.

TABLE OF CONTENTS

SECTION 1 - INTRODUCTION

This is an evaluation of a report entitled Impact of Stone Quarry Operations on Particulate Levels by PEDCo Environmental. The draft report was apparently written prior to and during September 1980 and then revised. The revised report is the one being evaluated.

This evaluation has been performed under an agreement with the Illinois Association of Aggregate Producers (IAAP) and is intended to be an objective evaluation of the methods used and the conclusions reached in the PEDCo report.

The organization of this document is the same as that used in the PEDCo report. The sections are titled and numbered identically and the comments provided will, in general, pertain to the corresponding material presented by PEDCo. All tables and figures referenced in this critique are contained in an appendix to it.

1.1 EXECUTIVE SUMMARY

In this section, the executive summary of the PEDCo report is examined. In their summary, PEDCo made certain observations and conclusions based on the data that they collected. First, they presented three project objectives and then they presented three project conclusions corresponding to the objectives. As detailed in this critique, support for their conclusions is weak, and many errors and incorrect analysis techniques appear in their report. In addition, the data have been often misapplied in an attempt to provide conclusions where none can be drawn.

The objectives of the PEDCo study are listed below.

1. To confirm or refute certain Illinois Environmental Protection Agency(IEPA) modeling results by measuring the actual impact of a typical stone quarry on ambient particulate levels.

2. To determine the relative impacts of suspected major emission sources at the quarry.

3. To estimate the effectiveness of commonly-used control measures in reducing the impact of quarry operations on particulate concentrations.

In order to achieve these objectives, the collection and analysis of many samples of total suspended particulate (TSP) had to be performed. These data were then averaged and otherwise treated statistically; several conclusions were drawn from the results.

It is our opinion that many of PEDCo's conclusions presented here and throughout the report are based on a limited data base, and none have been sufficiently supported by the study data to be considered definitive. Certainly, the data neither confirm nor refute dispersion modeling results pertaining to the quarry in question, as such site-specific modeling was not performed. Further, the data do not confirm the modeled results they were compared to, notwithstanding the admission that such a comparison was not proper.

Other listed objectives required the use of results from a separate, short-term sampling program at the quarry in order to be achieved. This sampling effort was too limited and site-specific to provide conclusive data to allow comparison with more normal quarry operations. Further, the general statements made often require qualification which is not presented. For instance, PEDCo states that

> "The crusher/storage area was identified as the largest contributing source."

What is not stated is that the crusher/storage area could not be effectively isolated from the impact of other quarry operations such as screening, conveying, material transfer, product loading and dust generation by trucks and equipment in the area. This other activity obscures the contribution of the three crushers and two storage stockpiles, which were also too close together to assess the impact of an individual source category.

The data used to determine the effect of watering on quarry impact were also misapplied and used for purposes for which they are not appropriate.

Consider the conclusion by PEDCo that;

> "Watering, as applied at the test quarry, did not reduce the overall impact around the quarry, but did reduce the concentrations immediately downwind of haul roads and the crusher/storage area by 31 and 26 percent, respectively."

First, the data collected by PEDCo indicate that the impact of the quarry was greater on days when control measures were applied than on days when no controls were implemented. This contradicts reality. Obviously, something is wrong with the data base. It is a known fact that watering as a control measure does reduce the generation of particulate matter. Second, the figures quoted for the reduction of particulate concentrations are calculated incorrectly and are based upon a statistical analysis which is performed incorrectly. In addition, the raw data as reported are inconsistent and too limited in quantity to provide an analysis with any reasonable degree of confidence attached to it.

In the description of the sampling methodology, PEDCo states that;

"Winds frequently reverse over 24-hour periods so that on many days neither pair of samples would be completely free of impact from the quarry (and therefore be valid upwind samples). To eliminate this problem and ensure virtually 100 percent usable data for the analysis of source contribution, directionally-actuated samplers were placed at each site. Directional controls (e.g., over a 90° range of wind directions) started the samplers when the wind direction was appropriate and prevented the samples from being exposed during crosswinds or periods of wind reversal."

PEDCo had to abandon this strategy of using directional samplers since their valid data recovery was far too low to meet their proposed guidelines. Their limited data base using directionally-activated samplers did indicate a decrease in quarry impact on days with control and an even greater decrease on days with little or no operation. Their subsequent analysis was of particulate sampling not specific to the quarry and presents no assessment of the large inherent error and small degree of confidence associated with the results. The results of this study cannot be used to draw conclusions; they can only suggest trends.

PEDCo did use the directional samplers for the determination of upwind concentrations on some days, but they were unable to use these data for the analysis of source contribution since they had difficulty with the functioning of the directional controllers. They also failed to collect data to show the time periods during which the directional samplers did run. To be comparable, the directional samplers would have had to run during the same time periods.

1.2 SELECTION OF QUARRY FOR SAMPLING

The quarry selected for this study had several obvious liabilities with respect to its use as the model in a definitive study. These shortcomings include proximity to farmed fields and an asphalt batch plant (sources of interference), a lack of normal spray trucks for controlling haul roads, the unpaved road and other sources of fugitive dust emissions, and the physical proximity of individual quarry operations which precluded sampling of individual storage piles or crushers. Nonetheless, it was chosen because of time constraints. If, as was stated in the report, this was the first comprehensive study of the air quality impacts from a quarry performed in this country, then more attention should have been paid to the selection of a representative quarry.

PEDCo's final statement in this section says that;

> "These conclusions are all site-specific and cannot be extrapolated quantitatively to other quarries."

It should be stated in the executive summary that their conclusions at best apply only to the quarry that was studied. The limitations of the analysis should also be stated, as well as their effect on the accuracy of the study results.

1.3 SCHEDULE

A sampling effort such as the one employed by PEDCo should be attempted only when sufficient time is available to perform all sampling under controlled conditions in order to minimize bias from other sources. In addition, in any definitive study, questionable samples should be discarded.

Time and resources should be allowed to assure collection of enough samples of demonstrable quality to support the conclusions drawn from the data.

Because of time constraints and equipment problems, compromises were made by PEDCo which degraded the usefulness of many collected samples. For example, potential biases were evident and at times, sampling conditions were unknown or inappropriate. These compromises included such things as the proximity to samples of sources of bias (haul road, new cut, batch plant, other plant operations, etc). In most cases, an insufficient number of samples was obtained, which negates the value of the analysis. Some analyses and comparisons presented by PEDCo are clearly improper. These consist of comparisons between samples collected using different methodology and analyses that begin the analysis under one set of conditions and change conditions in the middle of the analysis with no justification either presented or apparently possible. Such inconsistencies are detailed in subsequent sections of this critique.

Finally, there is the very real problem of whether enough samples were obtained to support all of the analyses presented by PEDCo with an acceptable level of confidence. Using the statistical analysis presented by PEDCo for determining the required number of samples, the minimum required number was obtained for only two of the analyses. This is an inadequate performance when the potential effect of the PEDCo report on the quarrying industry is considered. Additional samples should have been obtained or the limitations placed on the analysis by the reduced number of samples available should have been discussed.

1.4 PRODUCTS

The data analyses referred to in this section are discussed later in this evaluation.

SECTION 2 - SAMPLING METHODOLOGY

2.1 UPWIND-DOWNWIND APPROACH

The upwind-downwind sampling approach was utilized for all sampling in this study. PEDCo said of this method that;

> "Upwind-downwind sampling is a standardized technique that is widely used to measure fugitive emissions from sources that cover too large an area to be temporarily enclosed or sampled isokinetically along a cross-sectional profile."

However, PEDCo sampled around haul roads and the state highway. These are line sources and are good candidates for isokinetic (profiler) sampling. Isokinetic sampling eliminates some of the uncertainties of the upwind-downwind method and avoids the use of dispersion equations to determine source strength. Better control of source-receptor distances is possible, and some measure of plume dimension determination is done. No explanation for their failure to use isokinetic sampling around the line sources was offered.

2.2 FIXED NETWORK SAMPLING OF OVERALL QUARRY IMPACT

In the upwind-downwind method, samplers are placed a specified distance downwind from the center of activity of a source and also are placed upwind out of the range of impact of the source. For the total quarry impact sampling, which uses the difference between the concentrations collected at the two samplers as the impact, PEDCo chose distances of 0.5 and 0.7 km from a center of activity, presumed to be the crushing and processing area. The prevailing wind direction was specified as south-southwest, and samplers were also placed 0.5 and 0.7 km upwind of the center of activity. Although a new

cut is indicated as being close to the north set of samplers, no indication of activity at the new cut was presented, nor was discussion of the potential bias from activities at the new cut included.

Samplers activated by certain wind directions were also installed at these four sites and inhalable particulate (IP) samplers were installed at the 0.5 km sites. Since the directional samplers may not run full time, some assessment of the potential for passive loading during periods of no operation should have been performed. Further, the directional samplers, should not experience wide differences in running times. If they do, it is likely that local disturbances or equipment malfunctions may have biased the samples. Finally, the directional samplers should be running simultaneously, or their comparability is uncertain. For this reason, they should have been equipped with flow recorders to document their comparability.

An unpaved public road at the southern property line of the quarry may have biased the southern samplers. An additional sampler was to be located in order to assess the impact of the unpaved road, but this was never accomplished. For this reason, it appears that the extent of impact of this road on the samplers near it cannot be accurately assessed.

2.3 SHORT-TERM SAMPLING OF INDIVIDUAL QUARRY OPERATIONS

The upwind-downwind method of sampling was also used for these analyses. Little information is provided with respect to the distances between the individual quarry operations. From Figures 1 and 3, it is seen that the main entrance from the state highway, the main haul road and the crusher/storage area are all within a few hundred feet of each other. Due to this proximity, the potential for one source to impact the sampling of the

other sources is high. The use of only one upwind sampler to determine background for all three source areas is clearly inappropriate.

It is noted that all sources were sampled simultaneously. In order to minimize the effects of one source interfering with sampling at another, it would be most accurate to have all sources controlled (and preferably shut down) except for the one being monitored. This was not done, and therefore, it is likely that the source strengths estimated by sampling and analysis have some contribution from sources other than the one being assessed.

2.4 MONITORING ACTIVITY RATES AND METEOROLOGICAL CONDITIONS

The control technology utilized at the study quarry was described by PEDCo as the dumping of water from the bucket of a front-end loader on controlled areas once per day. This was the control technique for all controlled sources except for the crusher and conveyors, which were equipped with continuous water sprays. A more normal application of water on roads and open areas is by spraying from a tank truck on a regular schedule such as once per hour. The spray application is a more controlled method and was acknowledged by PEDCo to be the more efficient method. Thus, the control practices used during this study are not representative of normal control practices at a quarry. As a consequence, the study objectives were jeopardized.

The short-term sampling around the paved highway did not assess the application of controls. An appropriate control measure would have been the removal by sweeping of the trackout material and spillage from the highway. Some effect from control of the unpaved roads and quarry activities should be expected on the calculated emissions from the paved road, since

trackout and spillage would likely have been wetted from these control measures.

PEDCo started counting traffic by using traffic counters with sensing hoses that stretched across the road. Following the breakage of several hoses, they suspended the use of traffic counters on the paved (state) highway. No alternate method of traffic counting is given. It should be stated how the traffic count was obtained, as this was a variable under investigation. Table A-1 shows that the traffic count ranged from 340 to 1,015 vehicles during the short-term tests. How these numbers were obtained should be specified.

2.5 QUALITY ASSURANCE PROCEDURES

It was stated in the PEDCo report that 80 blank filters were returned unexposed to the lab and had an average weight increase of 3.6 mg. Although this was 20 percent above the acceptable tolerance of 3.0 mg, there is no indication that any action was taken to compensate for this out-of-tolerance condition. A 3.6 mg weight increase would add approximately 2.0 μg per cubic meter to the calculated concentration of a 24-hour sample at 45 cfm. This weight increase would impact a directional sample even more if it ran less than 24 hours, as was the case with virtually every directional sample.

SECTION 3 - DATA ANALYSIS METHODOLOGY

According to PEDCo, the data analysis methodology employed in this study was standard statistical analyses. The calculation of average concentrations for a data set is not a procedure that requires explanation. The effects of variables were evaluated by the analytical techniques of simple and multiple linear regression. Also, a statistical test was used by PEDCo to determine whether the relationships between certain variables and measured concentrations were significant.

As pointed out by PEDCo;

> "A statistically significant regression relationship between independent variables and particulate concentrations is no indication that the independent variables cause the observed changes in concentration, as both may be caused by a neglected third variable."

It should also be noted that the standard deviation of a set of samples, which is a measure of the spread between each individual sample point and the average value of the set of samples, is an important indicator of the usefulness of the analysis. The standard deviation is as large or larger than the average concentration often in this study. Thus, the statistical confidence that the average concentration calculated is equal to the true average concentration is very low.

SECTION 4 - RESULTS OF FIXED NETWORK SAMPLING AT QUARRY

4.1 NET DOWNWIND CONCENTRATIONS

The daily sampling produced 74 sets of samples from which upwind and downwind concentrations were obtained. The ideal situation is one where the upwind samples are totally free of impacts from the source being assessed and the downwind samples are collected under conditions where the samplers are always subject to impact from the source (as well as the background concentration). In such a case, one simply subtracts the upwind concentration from the downwind concentration to calculate the impact attributable to the source.

PEDCo chose instead to install all samplers close enough to the quarry so that any one could be used to determine the quarry impact depending upon prevailing wind direction. They justified this approach by the use of directional samplers. To minimize biases from other sources, these directional samplers would operate only during certain ranges of wind direction. Due to suspected equipment problems, PEDCo had to resort to the use of the 24-hour, nondirectional sample data in order to draw their conclusions. They did leave some of the directional data in the data base, making it inconsistent.

Since the objective of this study was to measure the actual impact of a stone quarry on ambient particulate levels, clearly the directional downwind sampler concentration minus the directional upwind sampler concentration is the appropriate calculation to determine net concentration and thus, the actual impact of the quarry. This was not done by PEDCo. Their conclusions were based on a mixture of directional and nondirectional upwind concentrations which were subtracted from the downwind 24-hour,

nondirectional concentration in order to calculate an impact for the quarry. This mix of data has not been shown to be statistically valid; it appears that a sufficient quantity of consistent samples was not obtained. Table A-3 contains the raw data.

Ideally, the directional samplers will run simultaneously, although a slight difference in run times will likely occur due to local conditions if the upwind and downwind samplers utilize individual starting mechanisms as was the case in this study. A large difference in run times indicates an anomaly in meteorological conditions or a malfunction of the directional starting units, either one of which should cause those samples to be deleted from this particular data base. If run times were so low as to cause large measurement errors, then these samples should be deleted also.

It is recognized that the sampling methodology described above is likely to be time consuming and resource intensive, but compromising the sampling only degrades data quality and diminishes the validity of the analyses performed with the data. If a compromise must be made, it should be accompanied by an analysis of its probable effect on data quality and accuracy. This was not done. PEDCo has treated the data statistically but they do not provide any indication of how well the results are expected to represent actual conditions. The high standard deviations indicate a low level of confidence in the available data.

The effect of watering as a control method was not detected by the 24-hour samplers, but was apparently detected by the directional samplers. However, since PEDCo was unable to obtain a sufficient number of the directional samples for proper analysis, they chose to base their conclusions on the nonspecific, 24-hour samplers. These data indicate that quarry impacts decrease when watering as a control measure is discontinued, which is a contradiction of known conditions.

In Table 3, the report presents net impacts segregated by level of dust control. In the presentation of averages, several data points from the directional samples are flagged as possibly biased, since the sampler ran less than 10 percent of the time. When data are suspect, they should be deleted from the data base. Removal of these particular suspect samples decreases the apparent impact of quarry operations anywhere from 14 to 26 percent. The following table compares the directional sampler impact data both as calculated and after removal of the suspect data.

NET DOWNWIND CONCENTRATION, $\mu g/m^3$

	NO WATERING		WATERING		NO OPERATION	
	0.5 km	0.7 km	0.5 km	0.7 km	0.5 km	0.7 km
$\bar{x}$	63.3	50.3	55.3	39.8	41.8	42.7
s	62.8	67.0	56.4	46.0	40.6	53.9
n	22	22	22	23	16	16
$\bar{x}$	54.5	41.6	46.1	29.3	34.1	34.7
s	48.5	54.3	50.2	31.6	27.8	44.9
n	21	21	20	21	15	15
$\Delta\bar{x}$	-13.9%	-17.3%	-16.6%	-26.4%	-18.4%	-18.7%

where
$\bar{x}$ = average net downwind concentration
s = standard deviation of sample set; and
n = number of samples.

In the above table, the top set of figures include the eight suspect samples, while the bottom set has deleted them. These few suspect samples significantly affect the average impact. In seven of the eight cases, the corresponding 0.5 km 24-hour samples are much lower than the suspect directional samples, indicating a systematic bias may exist when the

directional samplers operate less than ten percent of the possible sampling period.

The report states that the directional sampler concentrations did not seem to bear a consistent relationship with the 24-hour samplers. It then presents information (Table 4) that showed that the north and south directional samplers did not consistently operate the same amount of time each day. After comparing the running times with the continuous wind direction sensor data, they conclude that the wide fluctuations in measured concentrations may be due to problems with the directional control units.

After deleting certain samples from the directional sampler data base, PEDCo then segregated the remaining samples into subsets of directional data by control, which they denoted as poor control, good control, and no opertion, with the number of samples in the subsets being 15, 13, and 10. However, in the study design document, PEDCo stated that 27 samples would be required as a minimum in order to detect a 10 "g/m^3 impact from the quarry. Thus, their criteria for minimum number of samples was not met, and the closest subset size was more than 44 percent lower than the minimum required.

In order to continue the analysis, PEDCo used the results of the 24-hour sampling in order to base their conclusions. In examining the number of samples present, shown in Table 3, it is seen that in only two data sets out of six are the required number of samples present which are necessary for analysis with the required degree of accuracy.

From this examination of the collected data and the project objectives, it is clear that a definitive estimate of the impact of this quarry on ambient particulate concentrations cannot be made. In order to segregate the quarry impact, directional samplers must be used. In order to

attain a reasonable degree of confidence in the results, a minimum number of samples must be obtained from these directional samplers. In this study, PEDCo stated that 27 samples were required, but they used sample sets with less than this number in 4 of the 6 sample sets from which they based their conclusions. The sizes of those sample sets ranged from 20 to 25.

Another significant issue relates to the sampling periods of the directional samplers. In order for them to be directly comparable over a sampling period, they must run simultaneously. The PEDCo report states that there is no way of confirming that the directional units ran at the same time when their total run times did agree, and there is no way of knowing whether they ran during times of the day when the quarry was operational or shut down. Thus the averages provided by PEDCo for the directional data includes samples which may have been taken entirely during periods of no quarry operation, quarry operation, or a combination of the two. PEDCo should have explained why these data are of limited value and put them in an appendix rather than confuse the report by performing a partial analysis on them. They should also have specified that their conclusions were based on the results of the 24-hour sampling. After proclaiming the merits of the directional sampling so highly in Section 2, the fact that results from this sampling were unacceptable should have been made clear. PEDCo should state which data they are analyzing whenever they present a result.

Notwithstanding the contention that insufficient data gathered under appropriate conditions are available from the PEDCo study, some of the conclusions made using the available (albeit unsatisfactory) data are not consistent. The report states that the geometric mean of the chosen upwind samples is 64.5 $\mu g/m^3$, and that the value is above some unspecified value

for the background level of this rural area. It should be noted that the background level reference was an annual average, while the study data were all obtained during the 3-month period (May-July) likely to exhibit among the highest levels of particulate during the year.

The methodology used to select the upwind concentration was designed to obtain a value for each day sampled. If a valid concentration for the directional sampler was not available, a concentration from the 24-hour sampler was substituted. This happened on 56 occasions. The reason for employing the directional sampler was its ability to sample only during time periods where certain impacts could be included or excluded. The 24-hour sampler obtains an average sample subject to unknown impacts and biases. Thus, the substitution of 24-hour samples for directional samples is not consistent. It substitutes biased or unknown data for more properly obtained data in order to have a large enough data base to analyze. One cannot analyze a mixture of appropriate and inappropriate data and call the results conclusive.

PEDCo's conclusion on page 26 that:

> "quarrying, haul trucks, crushers, etc. have an incremental effect of about 15 $\mu g/m^3$ at 0.5 km and about 4 $\mu g/m^3$ at 0.7 km"

can only be reached by averaging the results of the 24-hour sampling under both control and no control conditions. As stated previously, these samples are not specific to the impacts from the quarry, and to be of any value, the incremental effect should be obtained for conditions of control or no control, not a combination of these conditions.

Comparing the impact from the 0.7 km directional sampler under controlled conditions with the 0.7 km directional sampler when the quarry was not operating shows a greater impact when the quarry was not operating (39.8 minus 42.7 = -2.9 $\mu g/m^3$). This is indicative of very unusual conditions or poor or insufficient data.

Similarly, the statement on page 28 asserting that the impact of the quarry dropped off rapidly with distance is based upon a comparison of the same 24-hour data in the same manner and is equally inappropriate. It appears that since the directional sampler data are of limited usefullness, the 24-hour data were used to support conclusions in order to allow the study to provide some conclusions concerning this quarry.

Several potential sources of interference in and around the quarry could have biased the sampling. These included the asphalt batch plant, an unpaved public road, a railroad line, a paved highway with unstabilized shoulders, and quarry operations at the new cut. The railroad and paved highway were dismissed under the assumption that, due to their being equidistant from the samplers, their impacts would be equally distributed to all samplers and thus cancel out. This is not necessarily true when the location of the quarry entrance is considered. The entrance is between the north and south sampler locations, and trucks entering and leaving the quarry will most likely go back in the same direction that they came from, and thus potentially impact only the north or south samplers. Due to trackout and the unpaved shoulder, the impact on a sampler can be significant. This became evident later on in the report when PEDCo reported that "emissions from the paved highway were surprisingly high." The statement was based upon sampling near the quarry entrance.

Regarding the unpaved road, the multiple linear regression (MLR) analysis indicated that the unpaved road could be adding a substantial concentration to the samplers south of the quarry on days with winds from the north, which would increase the apparent impact from the quarry. From Table 8, it is seen that the possible contribution attributable to the unpaved road on the 0.5 km directional south sampler is 5.6 $\mu g/m^3$. The 0.5 km 24-hour sampler, while theoretically less conclusive than the directional sampler, shows a much larger potential impact (23.1 $\mu g/m^3$). The IP sampler does not appear to support the presumption of potential bias, but the directional sampler would be expected to be the more conclusive sampler.

PEDCo has shown a possible contribution for the unpaved road, but they conclude that this is not happening by stating;

> "The data in total did not show a distinct difference in concentration as a function of which samplers were downwind."

They ignore another potential source of bias near the 0.5 km north samplers, the new cut. Just as the unpaved road could be impacting the south samplers, activity at the new cut, which is close to the north samplers, could easily be impacting these samplers and masking the impact from the unpaved road when comparing the net concentrations at the north and south 0.5 km samplers. Nowhere in the PEDCo report are the potential impacts of quarry operations at the new cut discussed.

Upon consideration of the above information, it appears, then, that no conclusions can be drawn concerning the impacts that may have come from the unpaved road. The study plan had apparently called for an additional sampler to be located so as to be useful in assessing the impact of the unpaved road,

however, this was not done. PEDCo has ignored the impact of an unpaved road even though they later conclude that unpaved haul roads are a significant source of fugitive particulate emissions.

PEDCo stated that due to the comparatively few number of days with winds from the north (30 percent of the total number of days), a moderate impact from the unpaved road on these days would not distort the overall results. This is not true; the results would be distorted, but the degree of distortion cannot be determined using data collected by this study. Further investigation on this subject is necessary.

Of the major potential sources of bias identified, it appears that there is no basis upon which to suspect that the batch plant and railroad were significant sources of bias to the analysis. The impact or lack of impact from the unpaved road, the new cut and the paved highway have not been substantiated in the PEDCo report.

4.2 EFFECT OF SOURCE-RELATED AND METEOROLOGICAL VARIABLES ON CONCENTRATIONS

In this section, PEDCo attempts to find significant correlations between measured concentrations and several independent variables suspected of being responsible for increases in total quarry particulate impacts. The variables analyzed included both source-related and meteorological parameters, and are listed below. Correlations calculated by PEDCo are contained in Tables 5, 6, and 7.

<ins>Source-related</ins>

1) Quarry production
2) Crushed rock shipped
3) Traffic volume on unpaved road
4) Implementation of control measures (watering)
5) Batch plant operations

<u>Meteorological</u>

1) Surface moisture content
2) Days since rain
3) Average wind speed
4) Winds greater than 12 mph
5) Prevailing wind direction

In order to arrive at the best estimate of the correlation between an independent and a dependent variable, the effect of the independent variable on the dependent variable must be statistically analyzed. The effect of the independent variable must not be obscured, or the correlation coefficient will be distorted. Since watering and rainfall are both expected to suppress the emissions of fugitive particulate, the correlations between watering and days since rain with net impact, analyzed for the period of the entire data set, distorted these correlation coefficients. This is because rain occurred during periods of no control, and watering took place on days that had no rainfall; the two variables were not independent.

Other inconsistencies in the calculation of correlation coefficients are also apparent. For instance, when evaluating the effect of an independent variable such as quarry production, the variable is expected to affect the dependent variable differently on days with and without control. Although it is expected to show a positive correlation under both conditions, the single coefficient determined is an average one and is not specific to either case. The same is true for the amount shipped variable. Some days had no operation, but the quarry did ship product. This distorts the correlation coefficient in another way, since any interdependence with quarry operation is absent on those days. In order to calculate the appropriate correlation coefficient, the correct procedure is to separate the data bases into control, no control and no operation. The correlation coefficients determined by analyzing the entire data set do not give a true value of the level of

correlation that exists when data for the conditions of control, no control or no operation are separated.

The MLR analysis concerning the 24-hour samplers is of little value. This is because additional factors obscure the exact relation between the independent variables and the direction-insensitive 24-hour samplers. As reported in the PEDCo report in Section 3.1,

> "A statistically significant regression relationship between independent variables and particulate concentrations is no indication that the independent variables cause the observed changes in concentration, as both may be caused by a neglected third variables."

One observation from the data in the correlation tables is made,

> "The only variable that was repeatedly significant at the 0.05 level was the amount of crushed rock shipped per day. This is an indication that the storage and loadout area had more impact than the pit area (represented by quarry production) on particulate air quality."

This is not necessarily true, since the presence of a significant correlation does not necessarily indicate a cause and effect relationship. In this case, many other activities may be occurring at the quarry in addition to storage and load-out such as crushing, screening, hauling and material transfer, and it is impossible to single out one activity as the cause in this manner.

It was stated in the report that the IP samplers had the highest multiple correlation of any of the particulate measurements. It should be noted that these samplers were not directionally activated, and in most cases, the 24-hour samplers had higher multiple correlations than the directional samplers.

4.3 SIZE DISTRIBUTION DATA

Some of the data presented in this section are incorrect. In the table that presents the average net IP concentrations, the values presented for the average and the standard deviation for the case where the quarry is not operating are shown to be 12.3 and 16.9 $\mu g/m^3$, respectively. Calculations based on the raw data presented in Table 9 yield values of 11.9 $\mu g/m^3$ for the mean and 17.1 $\mu g/m^3$ for the standard deviation. It is then stated that these impacts are very similar to those for TSP: 88, 80 and 84 percent, respectively. This is not true, and it is unclear what they are comparing.

One flaw in the data presented concerns the IP data. PEDCo has subtracted the upwind IP concentration from the downwind IP concentration and called the result the impact from the quarry. This is simply not true. What this "net concentration" represents is the difference between two IP samplers located on opposite sides of the quarry. This cannot be assumed to represent the quarry IP impact. The true upwind IP concentration is unknown; however, it is not likely to often be measured by an omnidirectional sampler located within 0.5 km of the center of activity of the quarry. In addition, the unpaved public road and the new cut will potentially bias these samplers, further obscuring the net quarry impact.

The only comparison possible is to subtract the upwind 0.5 km 24-hour sample concentration from the downwind 0.5 km 24-hour sampler concentration, and only during the time period where both the IP and TSP samplers ran. Wnen this is done, then at least the comparison is of concentrations obtained under similar conditions. The average TSP concentrations for each subset (when negative values are included as 0 $\mu g/m^3$ impact) are:

	Average $\mu g/m^3$	Standard Deviation $\mu g/m^3$	n
Poor control (no watering)	36.4	45.2	12
Good control (frequent watering)	40.6	53.6	16
Quarry not operating	9.5	11.6	12

Thus, the correct average IP/TSP impacts, using the correct IP average concentration for the data subset of quarry not operating are as follows:

Poor control (no watering)	67%
Good control (frequent watering)	53%
Quarry not operating	125%

The conclusion that watering did not appear to have a different effect on small particles than on total particulate is not substantiated. In fact, the data indicate that watering decreased the IP impact while it increased the TSP impact. This observation is also very poorly supported by the few data available, but it is based on data which are directly comparable rather than the improper comparison presented by PEDCo. The higher impact of IP over TSP shown also indicates a poorly collected or insufficient data base. The very high standard deviations calculated strongly state that too few data are available for this comparison.

PEDCo concludes this section by stating that

> "In summary, quarries were definitely shown to be a source of small atmospheric particles because of the high IP/TSP ratios and the average net downwind impact of 19.5 $\mu g/m^3$ of particles less than 15 μm diameter. These small particles appeared to be emitted by production-related and wind erosion sources alike (they occurred at high levels on production days but also on days when the quarry was not in operation), and responded much the same as TSP to dust control measures at the quarry."

In actuality, quarries were not definitely shown to be a source of small atmospheric particles. The data present are contradictory and minimal. It is not clear that PEDCo obtained the true quarry impact; what they obtained is an impact whose contribution from the quarry is unknown. The analysis of the data is inconsistent and the data do not support the conclusions.

SECTION 5 - RESULTS OF SHORT-TERM SAMPLING

5.1 TEST CONDITIONS

PEDCo's objectives for this portion of the project included the estimation of relative impacts of suspected major sources of fugitive emissions at the quarry and the estimation of the effectiveness of commonly used control measures in reducing these impacts. In this study, one of the major sources was a combination of the storage area activity, including screening, conveyor transfer points, truck usage, product load-in and load-out, the three crushers, and the aggregate stockpiles. This combining of sources reduces the comparability of findings with similar studies found in the literature, as most other data separate the effects of the different sources. Since Illinois has promulgated regulations concerning the control of fugitive emissions from aggregate stockpiles, study results specific to this type of source are clearly desirable.

In addition to the crusher/storage area, PEDCo sampled around the main haul road and around the state highway near the entrance to the quarry. These two sources are line sources (as opposed to point or area sources), and can be sampled more definitively using a profiler (isokinetic) sampler. This type of sampling has the advantage of making direct plume measurements, sampling isokinetically, providing information as to the concentration distribution in the plume and avoiding the requirement for dispersion equations to estimate source strength. In addition, the profiler sampling requires a sampling period on the order of 5 to 15 minutes, much less than the 1 to 3 hour requirement of the upwind/downwind methodology. This shortened sampling period greatly reduces the potential for biases from nearby sources and variable wind direction.

From the description of the individual sources studied in the short-term sampling effort and Figures 1 and 3, it is obvious that they are close enough to each other so that any one could be expected to interfere with the sampling of another. In particular, the opinion that one upwind sampler was deemed adequate to define the particulate loading of the approaching wind for all sources simultaneously is extremely difficult to accept. It would appear that in virtually any sampling alignment used, emissions from the most upwind source would likely bias the upwind particulate loading of one of both other sources.

5.2 TEST RESULTS

PEDCo states in this section that

> "The crusher/storage area had the greatest impact on particulate concentrations based on number of sampling periods with highest impact (11 out of 17) or on average net concentration at the three downwind distances. The haul road had the second highest impact, based on either its rankings in individual tests or its average concentrations. However, net concentrations decreased more rapidly with distance from the haul road than they did from the other two sources, leading to speculation that haul road emissions have larger size particles and therefore a smaller range of influence."

As stated previously, the crusher/storage area had many emission sources associated with it other than the crushers and storage piles. These sources include the operation of haul trucks, and it is not surprising that with all these potential sources, the highest impact was found. The statement that haul road emissions have larger sized particles is not adequately supported. Not nearly enough data are available to draw conclusions. Throughout Section 5 of the PEDCo report, conclusions are based upon insufficient data.

The observation was made in the report that the paved highway at the entrance to the quarry produced suprisingly high downwind concentrations. This is most likely due to the fact that conditions make this section of paved road different from most sections of paved road. First, since the road is at the quarry entrance, it is subject to trackout and spillage from the loaded trucks leaving the quarry. Second, the shoulder of this road is unstabilized, and finally, due to the proximity of the quarry, individual major sources in the quarry and a potential interferring outside source (batch plant), the downwind samples are likely impacted by sources other than the road itself. As mentioned earlier, the upwind concentration used has no documentation as to its validity for all three sources simultaneously.

The paved road net concentrations, from front to back, during the period of watering, averaged 697.6, 414.1 and 239.3 $\mu g/m^3$, respectively. This is a 65.7 percent decrease in concentration from front to back. The front to back concentrations during periods of no control were 444.7, 463.8, and 483.7 $\mu g/m^3$, respectively. This represents an 8.8 percent increase in concentration from front to back. This difference may indicate some effect of the watering of other sources, since trackout and spillage would be expected to be somewhat wetted and more likely to settle out than dry particulate matter.

Control of the paved road could have been accomplished by sweeping or even watering, however, this was not done. No reason was offered for not performing any control measures on the paved road.

The statement that net concentrations decreased most rapidly with distance from the haul road is only true in general. In the case of watering,

the percentage decrease from front to back sampled at the crusher/stockpile area was 68.3 percent. This exceeded the percentage decrease of the haul road under these conditions, which was 65.8 percent.

5.3 EVALUATION OF SHORT-TERM DATA

The evaluation of these data by PEDCo does not address certain issues that are important to the validity of the analysis and therefore, the strength of the conclusions drawn. Due to the high potential for any one source to impact another nearby source during sampling, the impact of a source being sampled should be isolated to the greatest degree possible from other potential interferants. This is done by the cessation of activity at nearby sources, or at least, the application of the maximum degree of control on other sources during sampling. This was not done in the PEDCo study. All sources operated simultaneously, and sources were either all controlled or all uncontrolled during sampling. This seriously degrades the potential for accurate and precise sampling results.

Another factor which must be considered is the number of samples which must be obtained in order to be statistically adequate. The method chosen by PEDCo to determine the required number for the total quarry impact was the use of the following equation:

$$n = \left(\frac{ts}{d}\right)^2$$

where n = number of samples required;

t = t-value statistic;

s = estimated standard deviation of particulate concentration; and

d = margin of error or lowest air quality impact that would be significant.

To estimate the average number of samples required statistically to analyze the crusher/stockpile area impacts, let us assume that t = 1.282 (this low value will minimize n). The standard deviation of all samples obtained for this source is 915.8. Since this source had large impacts, let us assume that d = 250 $\mu g/m^3$. With these liberal parameters, n should be 22 samples. Other calculations for sampling other sources yield even higher values for n. PEDCo used sample sets of 7, 10 and 17, which are clearly inadequate.

The reason for the large number of samples being required statistically is that the standard deviation, the measure of spread of the sampled concentrations, is so great. The larger the variation of magnitude between individual data points, the greater the number of points required to allow the statistical analyses to assign a reasonable level of confidence to its results. There are simply not enough sample points with which to make any defendable conclusions in this study. Even the use of these data to infer trends must be done with caution, as there is a very high degree of uncertainty.

For instance, the average net concentration for the uncontrolled impact of the haul road at the close-in samples is shown as 2471.2 $\mu g/m^3$ in Table 11. A statistic not presented by PEDCo concerning this value is that the analysis is only 90 percent confident that the true value of the average concentration lies in the range from 1619.6 to 3322.8 $\mu g/m^3$ assuming the concentrations are normally distributed. This is a very wide range for the 90 percent confidence interval.

Similar 90 percent confidence intervals could be prepared for the other subsets of sample data. These would all show similar wide ranges in which the true mean value has a 90 percent probability of being within the

range. Examination of the wide variety of conclusions that can be drawn from such a set of data quickly leads the analyst to the conclusion that more data are needed before an acceptable data base will be available. Before conclusions based upon these data are drawn, an analysis of the confidence one may place in the results must be made.

The short-term sampling data were then analyzed by simple linear regression to identify those independent variables that may have a significant correlation with downwind concentrations. The variables investigated were traffic volumes (quarry and highway), surface moisture content, days since rain, and wind speed. The correlation coefficients calculated appear in Table 12.

In the 39 tests for correlation of independent variables with downwind concentrations, ten variables exhibited a correlation that was deemed significant at the 95 percent level. What this means is that the analysis says that there is a 95 percent probability that the apparent correlation shown by the data is not due to coincidence. The value of the correlation coefficient, r, ranges from 0.51 to 0.85, with most correlation coefficients closer to the low end of the range. The lower the value of r, the lower the ability of the linear regression to define the correlation relationship. In this case, a value of 0.5 or less indicates no significant correlation.

The strongest correlation, that of days since rain on the closest haul road sampler, has an r value of 0.85. Inspection of Table 10 and Table A-1 reveals an inconsistency in the data for this determination. On June 17, the date of tests 8 and 9, it had been two days since rainfall had occurred. However, on June 16, it had been six days since rain had occurred, and on June 13, it was listed as four days since rain. Although the data as

presented yield an r value of 0.85 it is unclear what the correlation would be if the data were consistent.

It is interesting to note that the number of haul trucks did not have a correlation with particulate levels downwind from the haul road. PEDCo concludes:

> "the downwind concentrations measured in different tests were not closely related to the number of vehicles passing the samplers in those tests."

This is questionable since it has been proven that, in many studies, unpaved road emissions are related to the traffic volume on them. What is apparent in the PEDCo study is that insufficient data have been obtained. Although PEDCo has admitted the lack of correlation between traffic volume and particulate levels, on page 48, they use these poor data to calculate haul road emission rates in terms of vehicle miles traveled. This is inconsistent.

This is not very important, however, when one considers how little these data mean. It is unclear why the data were analyzed as one set, since PEDCo went on to perform linear regressions on subsets by control and no control, and used these regression constants to adjust the data. It appears that PEDCo used the analysis on the full data set to determine significant correlations between certain variables and particulate concentrations. They then adjusted data subsets to reflect average values of these significant variables. For this procedure to have any validity, these "significant variables" must still be significant by the regression analysis on the reduced data set, and as pointed out by PEDCo, with the reduced number of data pairs, a higher correlation is required for the variable to be significant at the 95 percent level ($r > 0.63$ for 10 pairs and $r > 0.75$ for 7 pairs).

In order to see if these correlations remained significant within the reduced data set, the linear regression analyses were performed on the haul road and days since rain data. The following correlations were calculated:

	SITES			REQUIRED
	FRONT	MIDDLE	BACK	R VALUE
Uncontrolled	0.76	0.48	0.71	0.63
Controlled	0.61	0.76	0.70	0.75

Therefore, the correlation was not significant for three of the six cases. In addition, the correlation between equipment in the crusher area and particulate levels at the front uncontrolled and controlled samplers were calculated to be 0.44 and -0.41, respectively. These are also not significant correlations; furthermore, one of these correlations is a negative number. A negative correlation indicates that a reverse correlation exists; i.e., more equipment operating in the crusher area reduces the particulate concentrations.

PEDCo stated that the correlation analysis performed on the subsets did not identify any additional significant relationships; indeed, as shown above, additional analysis deleted several of them. In separating the two sets of data they conclude that,

> ". . . the smaller sample sizes did result in a few apparent anomalies such as high negative correlations between activity rates and concentrations."

This was most certainly due to the fact that the data base was too small.

The value of seeking a correlation between days since rain and particulate levels during the period where watering took place is

questionable, since both events have similar effects and the watering would bias the constants of regression.

Following the analysis through, an attempt to arrive at some sort of average effect of watering was then performed. This was done both for the haul road and crusher/storage area. According to PEDCo, since some of the significant independent variables that greatly influenced particulate levels had fairly large differences in value from one data subset to the other, the true effect of control was obscured. Therefore, these variables were averaged, and the average values were used in the linear regression equations to provide average TSP values at every sampling site. These averaged values were then compared to get the difference between uncontrolled and controlled TSP concentrations. These differences were then averaged, and this figure became the final average effect of watering in reducing particulate concentrations. Of course, each time the data are averaged, the relationship between the average and the actual occurrence is weakened.

For the haul road, this analysis consisted of calculating the best fit straight line between the days since rain variable and the average particulate levels measured at the three sampling sites under controlled and uncontrolled conditions. Six equations were developed and are presented on page 47. Two of them are incorrect. Based on the data from Table 10, the equation for the first site, controlled should be:

$$TSP = 241.5\ DSR + 307.6$$

and the equation for the second site, uncontrolled should be:

$$TSP = 325.2\ DSR - 54.4$$

Incorporating the above equations into Table 13 changes the effect of watering the haul road with adjustments for days since rain from 31.1 to 42.8 percent.

When the limited data base, lack of correlation between variables, and extremely wide confidence intervals involved are taken into consideration, the value of any conclusions based upon these data is questionable.

With regard to the sampling of the paved highway the report states that,

> "Concentrations from the paved highway sampling did not have a substantial difference between the first 10 tests and the last 7 tests (5.4 percent lower for the latter tests). No control measures were applied to this source, so no difference was expected."

It is unclear what this means. As shown earlier, during the period of water, the paved road showed an average decrease from front to back of 65.7 percent, and the average net concentrations were quite different from those sampled during no control periods.

5.4 EMISSION ESTIMATES

In this section, the methodology for calculating emission rates was presented. No information is presented concerning whether it was assumed that sampling was done continuously on the plume centerline, and if not, how corrections were made. The average emission rates calculated are presented in Table 14.

PEDCo states that the haul road was the only source that exhibited deposition. This conclusion is supported only by the short-term sampling data which have been shown to be insufficient for the purposes of drawing conclusions with any reasonable degree of confidence. In fact, in Table 11, average net concentrations decrease with distance for all sources as would be

expected. There is no way of knowing whether these decreases are due to dispersion only or a combination of dispersion and deposition.

As was stated earlier, the paved road data were different during periods of watering and no watering. Emission rates for these two periods for the paved road should have been calculated, as they would be no less credible than those calculated for the other sources.

In discussing emission rates from the crusher/storage area, part of the anomalous emission rates calculated was attributed to dusty surfaces that the samplers were near. This sort of condition was not unique to the crusher/storage area; all of the samplers were subject to this type of interference. If their contention is true here, it is equally true concerning other uses of these data, and previous conclusions drawn from these data.

Finally, the report states,

> "The high test-to-test variability indicated by the relative standard deviations and sampling problems noted above such as turbulence in the plume and poorly defined source boundaries could be interpreted as producing unreliable results. However, the test-to-test variations and problems with these short-term sampling periods were no greater than those experienced with other fugitive dust testing efforts; results should be considered state-of-the art."

These statements are partially correct; the data are far too few to be able to produce reliable results, and this is amply demonstrated by high variability, overly large confidence intervals and contradictory results. It is also true that these same problems seem to plague many fugitive dust testing efforts, and that this effort may have been the best that could

have been done given the constraints of budget and schedule. However, this reasoning does not make the results produced accurate nor does it change the fact that this study is not definitive and cannot be said to provide substantiation of any modeling effort, fugitive emission factor, or control efficiency.

Furthermore, there are more accurate sampling methodologies available than the one used by PEDCo. Sampling of line sources and small area sources has been done several times using isokinetic profiler samplers for several years. Several firms are known to have performed this type of sampling, including Pacific Environmental Services, Midwest Research Institute, and TRC.

SECTION 6 - COMPARISON OF RESULTS WITH PREVIOUSLY AVAILABLE DATA

6.1 EMISSION FACTORS

In this section, the average uncontrolled emission rates calculated by PEDCo are compared to purported IEPA emission rates. A value for haul road emission rate has been calculated in units of pounds per vehicle mile. In Section 5, PEDCo states that the sampled data have no significant correlation with the number of vehicles on the road passing the sampler. They state that the emission rate was calculated from data at the first downwind distance where deposition is minimal. The comparable IEPA emission factor is shown in Table 16 as 18.0 lb/veh-mi. Using the factors provided and equation 1 from Table 15, the IEPA value is actually calculated to be 28.1 lb/veh-mi.

In determining the emission factor for crusher/storage area, PEDCo included as part of the factor only those equations pertaining to stock piles, stockpile maintenance and batch load-in/load-out. Other activities occurring in the area were crushing, screening, conveying and material transfer. Thus, the purported IEPA emission factor for this area is inadequate and misrepresented.

In examining the calculation of IEPA emission factors, PEDCo makes several assumptions without substantiation. For instance, for the paved road, they use a surface loading of 1000 lb/mile and an average vehicle weight of 3 tons. These assumed correction factors have no substantiation presented for their use. In particular, the assumption of an average vehicle weight of 3 tons is difficult to understand. This section of road is used by haul trucks which weigh many times this figure, even when unloaded. The choice of such a low vehicle weight must be supported by real data. Similarly, the assumed silt content must be substantiated. The assumed values for

these parameters serves to increase the gap between the so-called measured emission rates and the calculated rates that may be used by the IEPA. These assumed values make two correction factors applicable to the emission rate equation equal to 1 and thus, they drop out of the equation. No reason is given for assuming that the silt content of the storage piles, crushers and conveyors is 3 percent, but this is one-fourth and one-half of the average silt content measured (Table A-2) for the haul road and paved road, respectively.

In addition, the emission rates calculated for the various sources at this quarry can only be assumed to be representative of the time period in which they were determined. Even this assumption must be qualified since the supporting data are too limited to be definitive. However, the emphasis on the comparison seems to be misplaced. The true objective is to see how closley the IEPA emission factors approximate the conditions found at the quarry. PEDCo seems to be stating that where the measured and calculated emission rates differ, the IEPA emission rates are appropriate and the quarry is at fault for having improper emissions.

In order to be comparable, the IEPA emission rates should be calculated based strictly upon conditions as found at the quarry. Instead, some IEPA correction factors appear to have been chosen so as to eliminate their effect as correction factors such as the average vehicle weight, and the surface dust loading on the paved road. Also, the activity present at the storage/crusher area entails much more than those few activities upon which the IEPA calculated emission factor was based. Finally, the quantity of samples upon which the emissions rate determinations were based is clearly inadequate.

In discussing the adequacy of emission factors used by the IEPA, PEDCo states that they appear to be adequate for quarry air quality impact analysis. This conclusion is not supported by this study. The data gathered are inadequate, and the statistical analysis does not support such a conclusion.

6.2 AMBIENT IMPACT OF QUARRIES

In this section, PEDCo states their determination of the 3-month impact from this quarry based upon data from the 24-hour samplers. As shown earlier, these data are based on non-directional samplers and are at best, an inconclusive estimate. Although PEDCo originally espoused the virtues of directional sampling, they subsequently quietly dropped the directional data from use in any conclusion that they made.

The estimated impacts are compared with the results of computer dispersion modeling of some other quarry and judged to be approximately half of what the model would predict. It is not made clear whether the modeled results include the effect of particle deposition. In order to simulate the physics of particulate dispersion, deposition must be taken into account. Failure to do so will provide modeled results that overstate the expected concentration.

6.3 CONTROL EFFICIENCY OF WATERING

PEDCo lists four references in Table 17 that estimate the control efficiency of a regular watering schedule at 50 percent. Other literature is

available that presents measured control efficiencies at much higher levels, from 70 to 90 percent for regular watering. Two such references are listed below.

> "Fugitive Dust Assessment of Rock and Sand Facilities in the South Coast Air Basin" (California) Prepared for Southern California Rock Products Association and Southern California Ready-Mix Concrete Association, by Pacific Environmental Services, Inc.
>
> "The Atlantic Richfield Company Black Thunder Mine Haul Road Dust Study", Maxwell and Ives, Anaconda Minerals Company, Denver, Colorado. Presented at the 1982 Annual Meeting of APCA.

The control efficiency of watering at the quarry was first determined to be 72 and 60 percent, respectively, downwind of haul roads and the crusher/storage area. PEDCo states that these high efficiencies were obviously due in part to weather and operations differences. In order to correct for these biases, they adjust the data statistically to lower the apparent control efficiencies to 31 (actually 43) and 26 percent, respectively.

This statistical adjustment is not correct. First PEDCo arrives at a measure of what they consider significant correlation between independent and dependent variables, then they compute corrections based upon a different data set which includes negative correlations between the studied variables. This manner of analysis disqualifies any correction factors calculated from use in the statistical processing of data. It violates correct analysis technique.

In addition, all of this was done with an inadequate data base.

Finally, the control measures implemented at the quarry for this study were a waterspray at conveyors and the crusher and watering the haul roads and storage area. The watering was done once per day from the bucket of a frontend loader, and it is unlikely that it could achieve a 72 percent control efficiency on roads. It appears that this anomalous level of control was due to the limited data base from which several incorrect conclusions were drawn and observations made. One of the most questionable conclusions of this study with respect to control measures is the demonstration of the increased quarry impact on ambient air during periods of watering. As in so many places in this study, more data are necessary in order to draw conclusions.

SECTION 7 - SUMMARY AND CONCLUSIONS

This section summarizes briefly the material presented earlier and makes some comments on the analysis done in the PEDCo report, Impact of Stone Quarry Operations on Particulate Levels.

7.1 IMPACT OF QUARRY ON AMBIENT PARTICULATE CONCENTRATIONS

In order to measure the impact on ambient concentrations of fugitive TSP emissions from a stone quarry, sampling sites with 24-hour samplers and directionally activated samplers were established by PEDCo. The sites were located at distances of 0.5 and 0.7 km from the center of activity of the quarry, both upwind and downwind, in the prevailing wind direction for the 3-month sampling period. In addition, an IP sampler was installed at each of the two 0.5 km sites for comparison.

The original plan was to use the directional samplers as most representative of the impact from the quarry. Due to problems encountered with this equipment, not enough valid samples were obtained with which to perform the analysis at a reasonable level of confidence. Therefore, the data from the 24-hour samples were used to base conclusions in the analysis, although this was not made clear by PEDCo. The directional samplers were used to determine upwind concentrations.

Several deficiencies affect the analysis. These include,

- The 24-hour samples are not specific to impact from the quarry.
- Sources of potential bias (unpaved road, new cut, asphalt batch plant, unstabilized shoulders along the state highway, cartage traffic and farmed fields) were present that may have affected both of the 0.5 km sites.

- The method of determining the upwind concentration included the use of both 24-hour and directional samples, and thus the net impact was determined by comparing different methods of sampling.

- Only two of the six subsets of data achieved the minimum required number of samples for the analysis.

7.2 MAJOR EMISSION SOURCES AT QUARRY

PEDCo concluded that;

> "The crusher/storage area appeared to have a greater effect on air quality than pit operations such as the haul roads. In 17 short-term sampling periods of one to three hours each, samplers downwind of the crusher/storage area had the highest concentrations for 11 of the periods."

However, the activities in the crusher/storage area included cartage traffic, material transfer, product loadout, screening and conveying. Their conclusion is a misrepresentation since it implies that only crushing and storage occurs in this area, which is not the case.

PEDCo made several other conclusions concerning the short-term sampling. Some of the problems identified with the analysis used to draw these conclusions are listed below.

- The short-term sampling had far too few samples to be conclusive.

- A significant correlation does not mean that a causative relation exists.

- The statistical analysis performed on the short-term sampling was less than rigorous.

- The data base for the short-term analysis was inconsistent.

- The short-term analysis had several errors detected in it; more errors may exist.

- Data bases for control, no control and no operation were combined for comparison purposes when they should not have been.

7.3 EFFECT OF WATERING

PEDCo's study first found that watering reduced concentrations downwind from haul roads and the crusher/storage area by 72.4 and 60.3 percent, respectively. PEDCo then performed a statistical treatment which brought the numbers down to 31.1 and 25.6 percent, respectively. This statistical treatment included separating data bases, which introduced negative correlations (i.e., increased quarry equipment use reduces the calculated concentration). This is improper technique.

In addition, they adjusted data for days since rain during periods of source watering. This is improper procedure for determining the effect of rainfall or watering, since both occurrences have the same effect on particulate emission.

Finally, their calculations for reduction around the haul road were incorrect.

PEDCo's sampling for total quarry impact produced data which indicate that the average impact from the quarry increased on days when watering was done. Concerning PEDCo's findings for the effect of watering, the following facts should be noted.

- o The watering methodology was not standard practice.
- o The short-term analysis was inconsistent, incorrect, and based on insufficient data.
- o The 24-hour measured impacts contradict expected results.

7.4 SIZE DISTRIBUTION OF AMBIENT PARTICULATE NEAR QUARRY

The IP/TSP ratio determined by PEDCo at the two 0.5 km locations were higher than the average reported by the USEPA. This indicates that the large particles have settled out by the time they get to this distance, according to PEDCo.

The data are not conclusive here either. Other factors which must be considered include the following.

- o The average IP/TSP ratio reported by the USEPA was for an urban area. This was a rural area. The source type for the area being reported by EPA is unspecified.
- o PEDCo reported earlier that the quarry impact fell by 50 percent at the 0.7 km distance. It is impossible to tell whether this reduction is strictly due to dispersion (unlikely), or whether deposition also occurred.

7.5 UPWIND CONCENTRATIONS

PEDCo stated that the geometric mean of upwind concentrations was about equal to rural background for an agricultural area in Illinois. They also state that upwind samples may have been impacted from the quarry on days with variable winds. They neglected to state that sampling was done during the 3-month time period during which maximum fugitive impacts could be expected.

The upwind samples were taken from the 0.7 km samplers if a valid sample was available. The directional sample was used if the sampler ran more than twelve hours, otherwise the 24-hour sample was used. If 0.7 km data were not available, the 0.5 km samplers were used to obtain the upwind sample. The north samplers at the 0.5 km distance were on the quarry property and were close to the new cut, and the south 0.5 km samplers were close to an unpaved

public road The upwind samples should have been obtained only from an area where quarry impact should not be expected. If impact from the quarry was suspected, the data should have been deleted. This was not done.

7.6 EFFECTS OF OTHER INDEPENDENT VARIABLES

The report states that only the amount of crushed rock shipped was significantly correlated with the 24-hour net impact. For the short-term impact, PEDCo stated that equipment in the crusher area and meteorological variables had significant correlations.

The lack of correlations found between quarry production, traffic on unpaved roads or watering and downwind total-quarry particulate concentrations is hard to imagine. This indicates a very unusual quarry or a lack of sufficient data. In either case, the data cannot be considered representative of a typical stone quarry or their operations, since it is a known fact that these variables do affect particulate emissions from this type of source.

The calculation of correlation coefficients from the short-term sampling was done on a data set including samples from time periods with control and no control, and thus, the correlation coefficients computed are not specific to these specific conditions. Not enough valid data are available to make any conclusions concerning the results of the short-term sampling in any case.

7.7 GENERAL CONCLUSIONS OF DAMES & MOORE

The objective of this critique is to assess how closely the PEDCo study came to meeting its stated objectives. Since a study such as this can have a tremendous influence on future regulation of an industry, it is

extremely important that it be done with the utmost attention to detail and logical, correct methodology. The study must be carefully planned in advance, and approved plans must be strictly adhered to. Finally, the results of such a study should include an assessment of the accuracy, usefulness and limitations of the analysis.

The PEDCo study and report fail to satisfy these requirements, and the results are not shown to be conclusive or representative of typical stone quarries. Some of the shortcomings of the study are:

1. PEDCo was unsuccessful in the use of their proposed directional sampler methodology. Although they presented directional data, they based their conclusions on the nondirectional sampler data;

2. They failed to perform essential sampling required to assess the impact of an unpaved road on sampled results;

3. The analysis used several incorrect techniques in the statistical processing of data;

4. Several inconsistencies and errors are apparent in the data presented;

5. The multiple linear regression (MLR) analysis indicated insignificant correlation between quarry operations and meteorological parameters. Such parameters are known to affect emissions with the sampled results;

6. Far too few samples were obtained for an acceptable level of confidence in the short-term analysis;

7. Several conclusions were based on the comparison of data which are not directly comparable;

8. No assessment is provided of the accuracy, usefulness or limitations of the study results;

9. Invalid or inappropriate data are included in several analyses where they shoud be deleted;

10. Some sampling methodology used was not state-of-the-art; and

11. Upwind concentrations for the short-term sampling for all sources were taken from one sampler, however, source proximity should dictate against this procedure.

The PEDCo study fails to meet its primary objective, that of confirming or refuting modeled results by actual measurement. No appropriate modeled results are presented. The actual measurements obtained by PEDCo have inconsistencies and potential sources of bias contained in them.

Two secondary objectives were stated, both of which required the analysis of the short-term data. The first was to determine relative impacts of major emission sources at the quarry. PEDCo assigned relative levels of impacts, but these were based on very limited data. In addition, one source category (crusher/storage area) consisted of too many separate quarry activities to make comparison of it with any single activity or common group of quarry activities meaningful. PEDCo also calculated emission rates, but at this point the limited data and inconsistencies render them unfit for any definitive purpose. Similarly, a statistical analysis that attempted to investigate correlations between certain activities at the quarry and particulate concentrations produced inconsistent and inconclusive results.

The final stated objective was to estimate the effectiveness of commonly-used control measures in reducing particulate concentrations. The primary control measure used at the quarry studied was an inappropriate substitute for a proper water truck. The sampling did not isolate source impacts by operating only one source at a time or controlling those not being sampled for uncontrolled impact. All sources operated simultaneously, either all controlled or all uncontrolled. This is poor sampling technique.

The short-term control analysis again used insufficient data and inconsistent methodology, and produced inconclusive results. The control analysis for total quarry impact indicated that not watering produced a

greater degree of control than watering did. This contradiction is an incorrect finding of the study, as watering is a commonly used control measure.

In summary, the results of the PEDCo study are based on an inadequate data base, and improper statistical treatment. In addition, more accurate sampling methodologies were available but not used. As a consequence, the study objectives were not adequately met.

Summary of IEPA Comments on

"Impact of Stone Quarry Operations on Particulate Levels"

Summary of
IEPA Comments on
"Impact of Stone Quarry Operations
on Particulate Levels"

State-of-the-art quality sampling techniques were used in this analysis and, in general, the study and its conclusions are basically sound. In spite of severe time constraints, limited resources, and a broad scope of work, the contractor completed the work on time.

The results of the study do not suggest that IEPA shall abandon currently available emission factors or substantially revise the modeling techniques that are used for analyzing the air quality impacts of particulate emissions from stone quarries. On the contrary, most of the results and conclusions are generally supportive of analytical techniques that IEPA has been using for some time.

However, in order to clarify some points of potential misunderstanding and possibly eliminate some of the concerns that may be generated by the results of this study, the following comments are offered on certain aspects of the report.

Time and resource constraints limited the duration of this project to three months of field sampling which had to be conducted at only one site. It was never intended to be "the definitive study," completely documenting the impacts of all sources of particulates at a stone quarry. Rarely in the field of particulate investigations are the results of a single study sufficiently overwhelming that they radically alter findings based on previous knowledge or experience. Usually, new findings must be confirmed by several studies before related emission factors and modeling procedures are fully developed or substantially revised.

Most particulate studies are intrinsically plagued with high background levels, multiple source interferences, and large variability in the levels and composition of the particulate matter. These problems generally result in poorer statistics, i.e., lower confidence levels, being developed from the study data. When data are analyzed, the level at which differences are significant (and thereby the level at which cause and effect can be inferred) must be subjectively set by the person conducting the analysis. In the case of the quarry study, PEDCo personnel were in that position. Ultimately, those using the results of the study must determine if the confidence levels were set adequately for the purpose they have in mind.

For this study, no alternate quarry sites were readily available. The Illinois Association of Aggregate Producers (IAAP) assisted INR and the IEPA in finding an appropriate site for the project. They proposed only one site (the one that was used) prior to the time that the study was to begin. At that time, it appeared to all interested parties (i.e., INR, IEPA, and IAAP) that the site would be adequate. Although there is no "typical quarry" in terms of size or spatial configuration, all quarries generally contain similar elements, i.e, haul roads, storage piles, bare areas, rock crushers, etc.

Following the first draft of the PEDCo study, several criticisms of the study site surfaced. Among these criticisms were the following: too many interferring sources, non-standard watering of the haul roads, the crusher operation was too near storage piles and haul roads, etc. The fact that there is some truth to all of these criticisms is not overly disturbing to those who have had experience in source monitoring studies designed to measure the impact of particulates. There is no "ideal site" which is free of all interferences. Given the situation, the contractor responded to these interferences reasonably and adjusted the sampling approach to minimize, to the extent possible, the negative impact of the interferences associated with the site.

The impacts of the quarry sources were evaluated using a technique which incorporated placement of particulate monitors both upwind and downwind of individual sources. Directional and non-directional hi-volume total suspended particulate (TSP) monitors were used as well as size selective monitors. The overall impact of the quarry and the localized impact of specific sources were inferred from the differences between the upwind and downwind monitors. This is a proven and accepted method for conducting particulate studies of this type. While it might be argued that isokinetic sampling of the plume profile would have been more appropriate for some of the sources in the quarry, a profile monitoring system was not available for this study, and there is no indication that it would have produced better results. As with any monitoring method, the isokinetic profilers have disadvantges. True isokinetic sampling, which can only be conducted if the wind speed and direction are fairly constant, greatly limits the number of hours that can be used. An additional source of uncertainty is that the isokinetic measurements must be adjusted in order to be directly comparable to the hi-volume sampler values on which the air quality standards are based.

PEDCo used a standard approach in their analysis of the quarry operations. A long list of variables were statistically analyzed, using significance tests and multiple linear regression techniques. The contractor appeared to be straight-forward in the presentation of the results, being quick to point out weak statistical relationships. The emission factor comparisons were reasonably consistent, giving further credence to the validity of methods used in this study. The high emission factor found for paved roads can probably be attributed to the large amount of "mud carryout" from the quarry. The results of the study compared well with previous IEPA modeling results.

In conclusion, the methods and results of this study should be considered state-of-the-art. The study results were consistent with other fugitive dust studies that have been conducted around the country.

Final Amendment to Air Pollution Control

Regulations to Rule 203 (f) of Chapter 2 -

Fugitive Particulate Emissions

from Industrial Sources

ILLINOIS POLLUTION CONTROL BOARD
October 4, 1979

IN THE MATTER OF:	)	R78-11
Fugitive Particulate Emissions from Industrial Sources (Proposed Revision of Rule 203(f) of Chapter 2)	)	

ORDER OF THE BOARD (by Mr. Goodman):

The Board hereby adopts the following amendment to Rule 203(f) of Chapter 2.

FINAL ORDER

203(f) Fugitive Particulate Matter

(1) No person shall cause or allow the emission of fugitive particulate matter from any process, including any material handling or storage activity, that is visible by an observer looking generally toward the zenith at a point beyond the property line of the emission source.

(2) Except for those operations subject to Rule 203(d)(8) (Grain-Handling and Grain-Drying Operations), Rule 203(f)(3) shall apply to all mining operations (SIC major groups 10 through 14), manufacturing operations (SIC major groups 20 through 39), and electric generating operations (SIC group 491), which are located in the areas defined by the boundaries of the following townships, notwithstanding any political subdivisions contained therein, as the township boundaries were defined on October 1, 1979, in the following counties:

Cook: All townships

Lake: Shields, Waukegan, Warren

DuPage: Addison, Winfield, York

Will: DuPage, Plainfield, Lockport, Channahon, Peotone, Florence, Joliet

Peoria: Richwoods, Limestone, Hollis, Peoria, City of Peoria

Tazewell: Fondulác, Pekin, Cincinnati, Groveland, Washington

Macon: Decatur, Hickory Point

Rock Island: Blackhawk, Coal Valley, Hampton, Moline, South Moline, Rock Island, South Rock Island

LaSalle: LaSalle, Utica

Madison: Alton, Chouteau, Collinsville, Edwardsville, Fort Russell, Godfrey, Granite City, Nameoki, Venice, Wood River

St. Clair: Canteen, Caseyville, Centerville, St. Clair, Stites, Stookey, Sugar Loaf, Millstadt.

(3) On and after December 31, 1982, potential sources of fugitive particulate matter shall be maintained and operated as follows:

(A) All storage piles of materials with uncontrolled emissions of fugitive particulate matter in excess of 50 tons/year which are located within a facility whose potential particulate emissions from all sources exceed 100 tons/year shall be protected by a cover or sprayed with a surfactant solution or water on a regular basis, as needed, or treated by an equivalent method, in accordance with the operating program required by Rule 203(f)(3)(F).

Exception: Subparagraph (A) of this Rule 203(f)(3) shall not apply to a specific storage pile if the owner or operator of that pile proves to the Agency that fugitive particulate emissions from that pile do not cross the property line either by direct wind action or reentrainment.

(B) All conveyor loading operations to stor-

age piles specified in Rule 203(f)(3)(A) shall utilize spray systems, telescopic chutes, stone ladders, or other equivalent methods in accordance with the operating program required by Rule 203(f)(3)(F).

(C) All normal traffic pattern access areas surrounding storage piles specified in Rule 203(f)(3)(A) and all normal traffic pattern roads and parking facilities which are located on mining or manufacturing property shall be paved or treated with water, oils, or chemical dust suppressants. All paved areas shall be cleaned on a regular basis. All areas treated with water, oils, or chemical dust suppressants shall have the treatment applied on a regular basis, as needed, in accordance with the operating program required by Rule 203(f)(3)(F).

(D) All unloading and transporting operations of materials collected by pollution control equipment shall be enclosed or shall utilize spraying, pelletizing, screw conveying, or other equivalent methods.

(E) Crushers, grinding mills, screening operations, bucket elevators, conveyor transfer points, conveyors, bagging operations, storage bins, and fine product truck and railcar loading operations shall be sprayed with water or a surfactant solution, utilize choke-feeding, or be treated by an equivalent method in accordance with an operating program.

Exception: Subparagraph (E) of this Rule 203(f)(3) shall not apply to high-lines at steel mills.

(F) The sources described in paragraphs (f)(3)(A) through (f)(3)(E) shall be operated under the provisions of an operating program prepared by the owner or operator and submitted to the Agency for its review by December 31, 1982. Such operating program shall be designed to significantly reduce fugitive particulate emissions.

As a minimum the operating program shall include the following:

1. the name and address of the facility;

2. the name and address of the owner or operator responsible for execution of the operating program;

3. a map or diagram of the facility showing approximate locations of storage piles, conveyor loading operations, normal traffic pattern access areas surrounding storage piles and all normal traffic patterns within the facility;

4. location of unloading and transporting operations with pollution control equipment;

5. a detailed description of the best management practices utilized to achieve compliance with Rule 203(f), including an engineering specification of particulate collection equipment, application systems for water, oil, chemicals, and dust suppressants utilized and equivalent methods utilized;

6. estimated frequency of application of dust suppressants by location of materials;

7. and such other information as may be necessary to facilitate the Agency's review of the operating program.

The operating program shall be amended from time to time by the owner or operator so that the operating program is current. Such amendments shall be consistent with this Rule 203(f) and shall be submitted to the Agency for its review.

(4) If particulate collection equipment is operated pursuant to Rule 203(f)(3), emissions from such equipment shall not exceed 0.03 gr/dscf (0.07 grams per cubic meter).

(5) Rule 203(f)(1) shall not apply and spraying pursuant to Rule 203(f)(3) shall not be required when the wind speed is greater than 25 miles per hour (40.2 kilometers per hour). Determination of wind speed for the purposes

of this rule shall be by a one-hour average or hourly recorded value at the nearest official station of the U.S. Weather Bureau or by wind speed instruments operated on the site. In cases where the duration of operations subject to this rule is less than one hour, wind speed may be averaged over the duration of the operations on the basis of on site wind speed instrument measurements.

(6) No person shall cause or allow the operation of a vehicle of the second division as defined by Ill. Rev. Stat. ch. 95 1/2, §1-217, as revised, or a semi-trailer as defined by Ill. Rev. Stat. ch. 95 1/2, §1-187, as revised, without a covering sufficient to prevent the release of fugitive particulate matter into the atmosphere, provided that this paragraph (f)(6) shall not pertain to automotive exhaust emissions.

IT IS SO ORDERED.

Mr. Dumelle concurs.

Mr. Werner dissents.

I, Christan L. Moffett, Clerk of the Illinois Pollution Control Board, hereby certify the above Order was adopted on the 4th day of October, 1979 by a vote of 3-1.

Christan L. Moffett

Christan L. Moffett, Clerk
Illinois Pollution Control Board

REPORT DOCUMENTATION PAGE	1. REPORT NO. IL ENR/RE 83/14	2.	3. Recipient's Accession No.

4. Title and Subtitle

Impact of Stone Quarry Operations on Particulate Levels and Comments

5. Report Date June 1983

6.

7. Author(s)

Walter Zyznieuski, Editor

8. Performing Organization Rept. No.

9. Performing Organization Name and Address

Department of Energy and Natural Resources
325 W. Adams Street
Springfield, Illinois 62706

10. Project/Task/Work Unit No.

11. Contract(C) or Grant(G) No.

(C)

(G) 10.085

12. Sponsoring Organization Name and Address

Department of Energy and Natural Resources
325 W. Adams Street
Springfield, Illinois 62706

13. Type of Report & Period Covered

14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)

The Illinois Environmental Protection Agency (IEPA) has performed dispersion modeling analy that have indicated that fugitive dust emissions from quarries contribute to violations of particulate standards in several nonattainment areas throughout the state. However, the generation of emissions from quarries and the dispersion of the emissions away from the sit are not well understood. In response to this problem, the Department of Energy and Natural Resources contracted with PEDCo Environmental, Inc., to perform air quality analysis from a quarry. The primary purpose of the study was to confirm or refute these modeling results b measuring the actual impact of a typical quarry on ambient levels.

After the study was completed, two opposing viewpoints emerged and many questions were rais as to the correct monitoring techniques, field monitoring locations, data gathering and fin analysis. This document contains opposing viewpoints of PEDCo's final results as well as th actual report by PEDCo.

The document is broken down into four sections: 1) PEDCo study, 2) Critique of the PEDCo study by Dames and Moore for the IAAP, 3) IEPA comments on the PEDCo study, and 4) the amendment to Rule 203(f) of IPCB Chapter 2, Fugitive Particulate Emissions from Industrial Sources

17. Document Analysis a. Descriptors

Quarrying
Air Pollution
Dust
Particle Size
Illinois

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group 1302

18. Availability Statement:	19. Security Class (This Report)	21. No. of Pages
No restriction on distribution. Available at Illinois Depository Libraries or from National Technical Information Service, Springfield VA	Unclassified	150
	20. Security Class (This Page) Unclassified	22. Price

(See ANSI–Z39.18)

OPTIONAL FORM 272 (4
(Formerly NTIS–35)
Department of Commerc